

Flooded Dark Matter and Core/Cusp with Fermionic Dark Matter

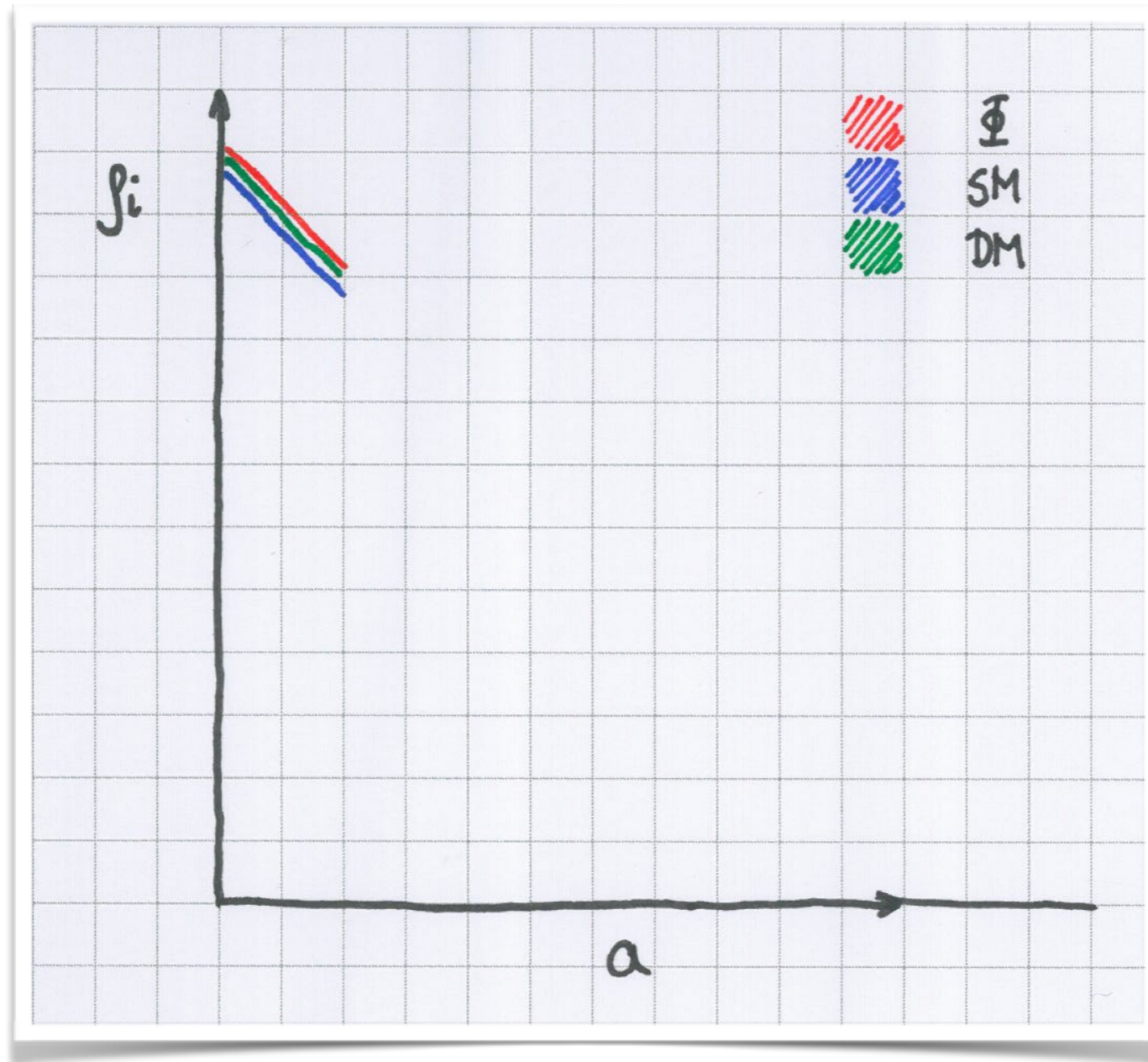
L. Randall, J. Scholtz, J. Unwin

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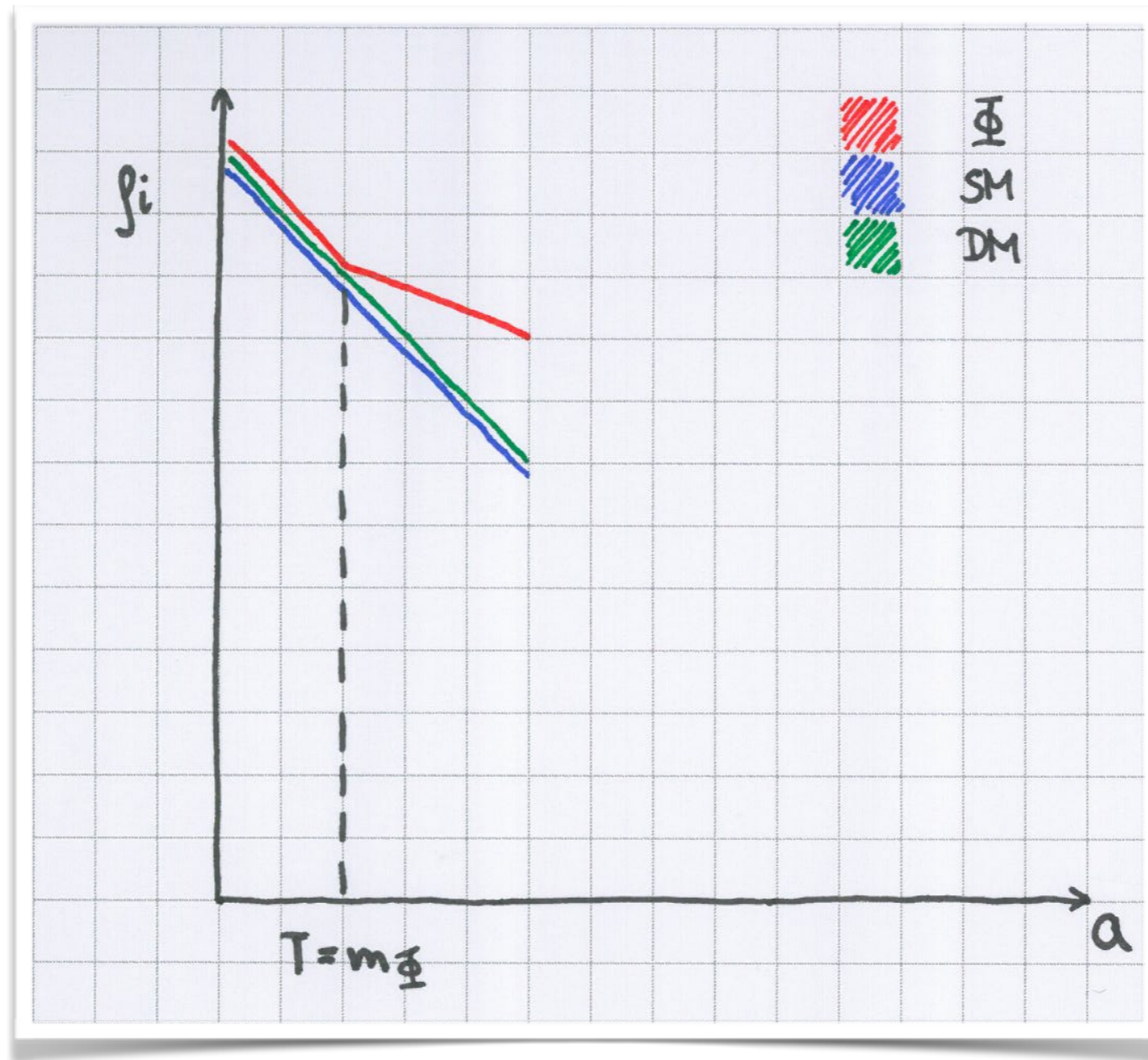
more to appear soon

Fermilab

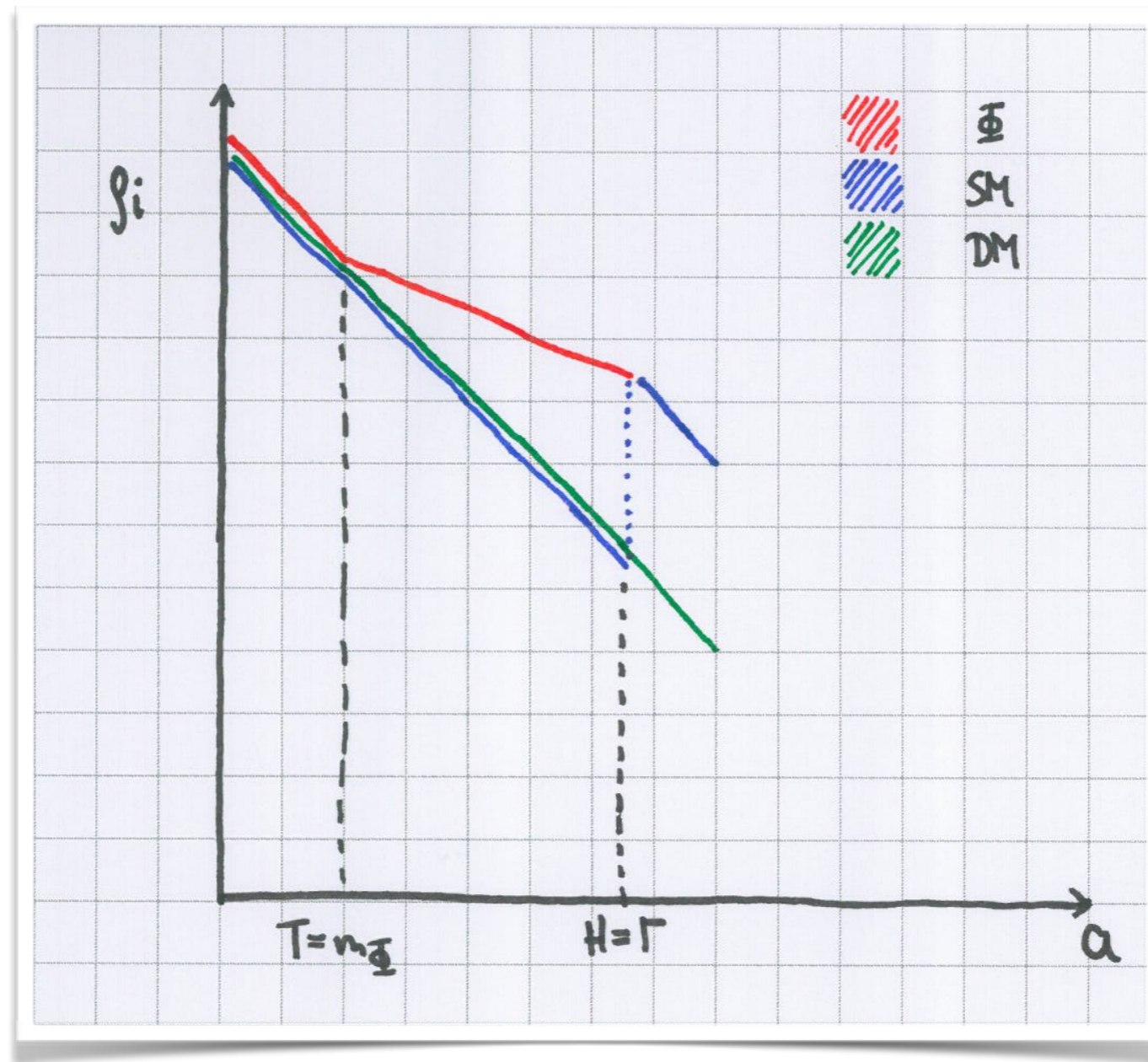
Consider a scenario



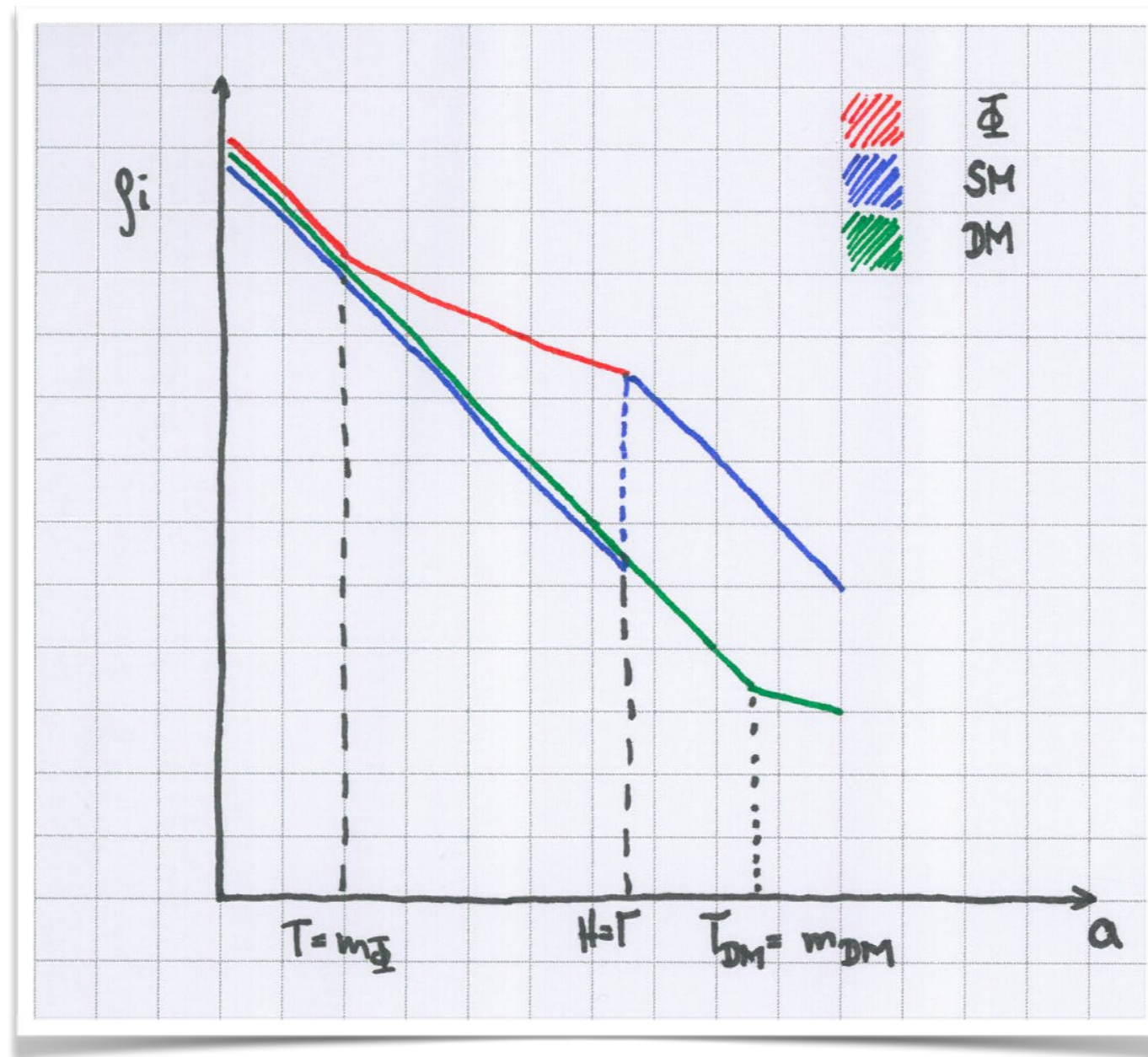
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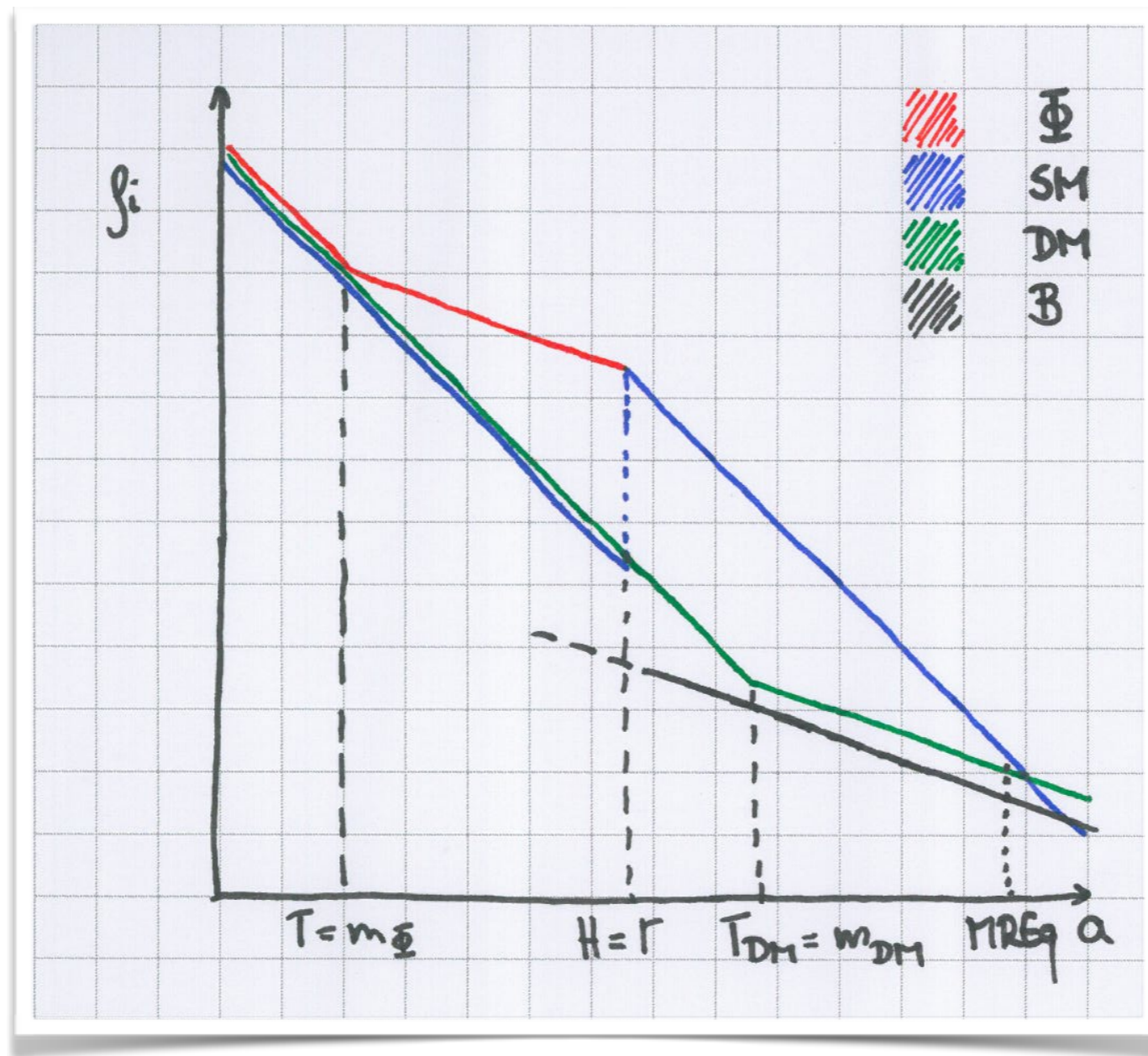
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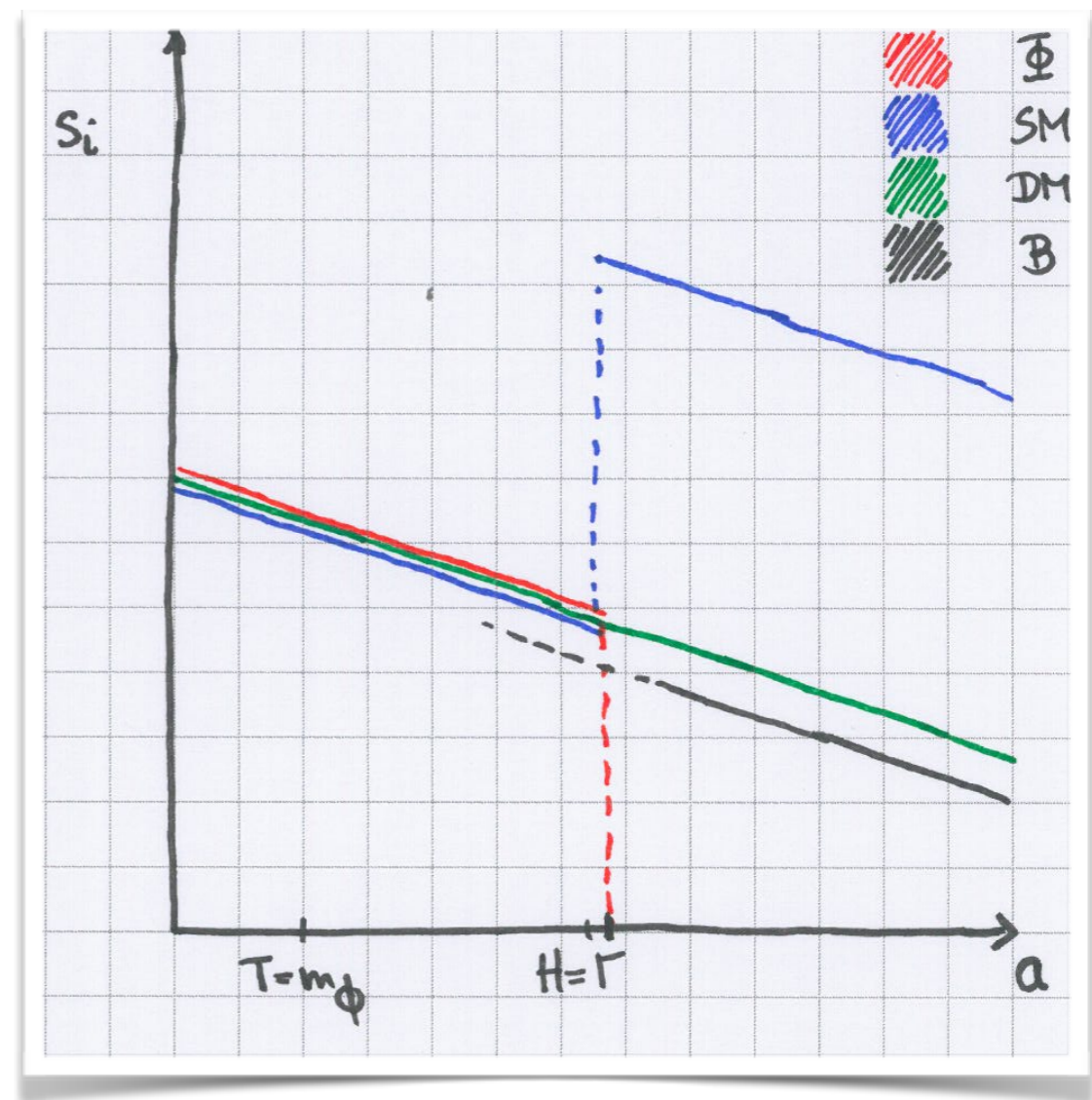
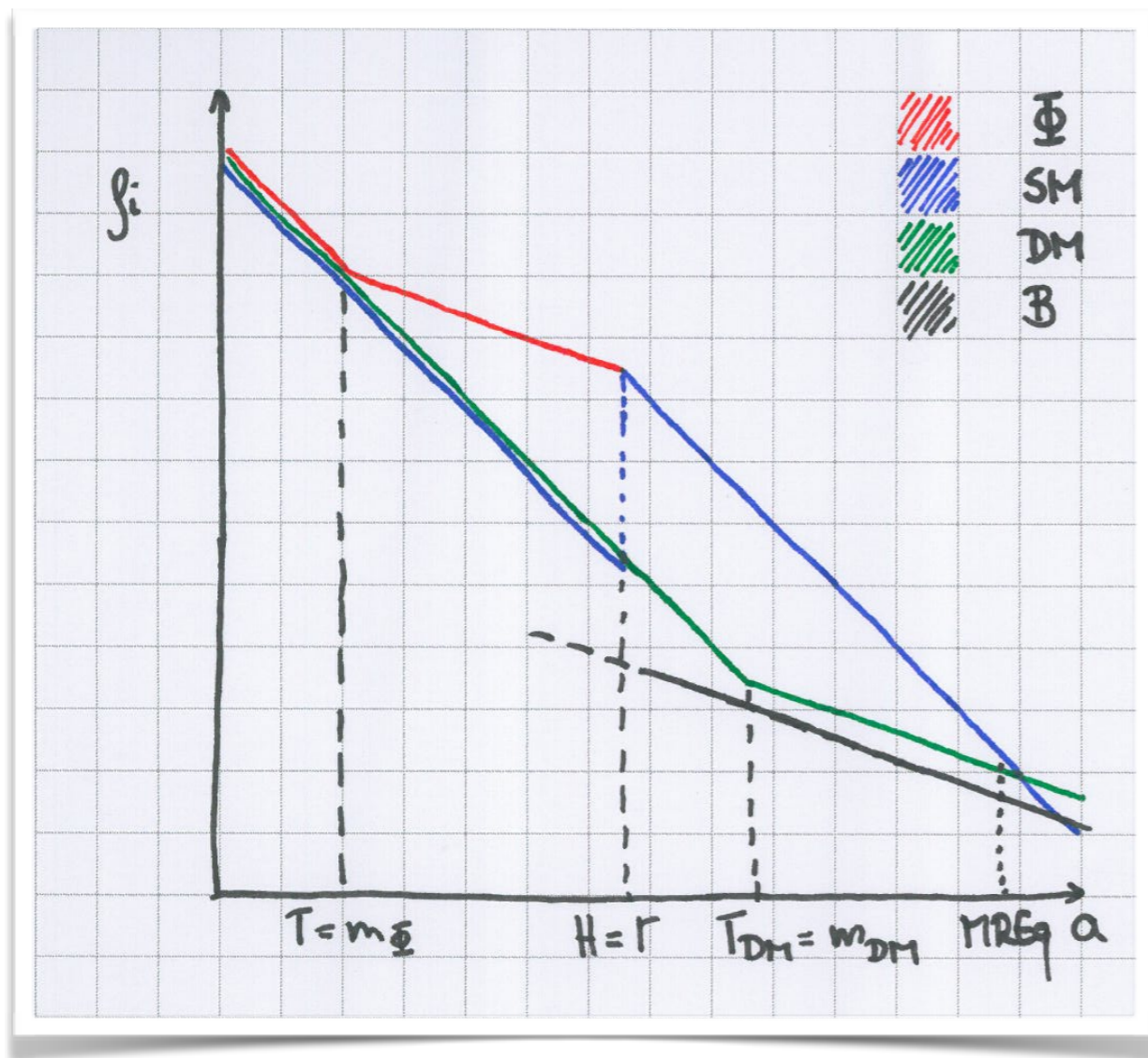
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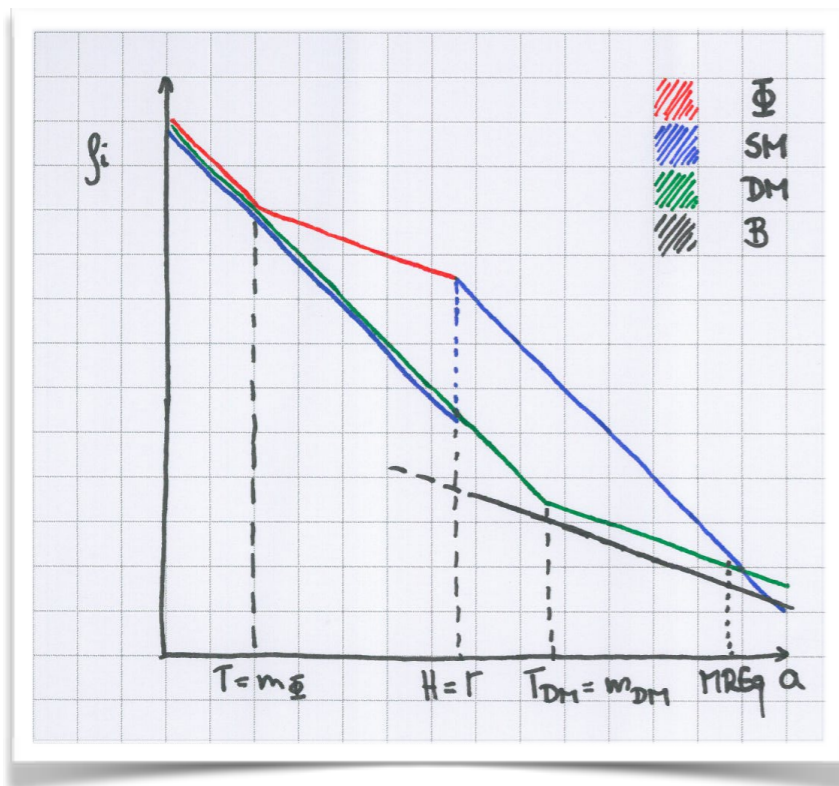


How about entropy?



What did we achieve?

- We started with a fairly **generic initial condition**.
- We have set the **relic energy density** of DM by a **lifetime** as opposed to interactions.
- Arranged for a scenario in which **Standard Model dominates the entropy** of the Universe.



- All other sectors are now **colder** than the visible sector:
 - Dark Sector relativistic dofs are now okay.
 - Nice setup for Freeze-in
 - Light fermionic DM avoids free-streaming bounds. This could resolve the **core/cusp** problem.

The Pesky Details

1. Calculate the relic density (Ω_{DM}/Ω_B) in terms of parameters of our framework.
2. Calculate the reheat temperature (allow Baryogenesis*).
3. Calculate the ratio of temperatures of DM and SM sectors.

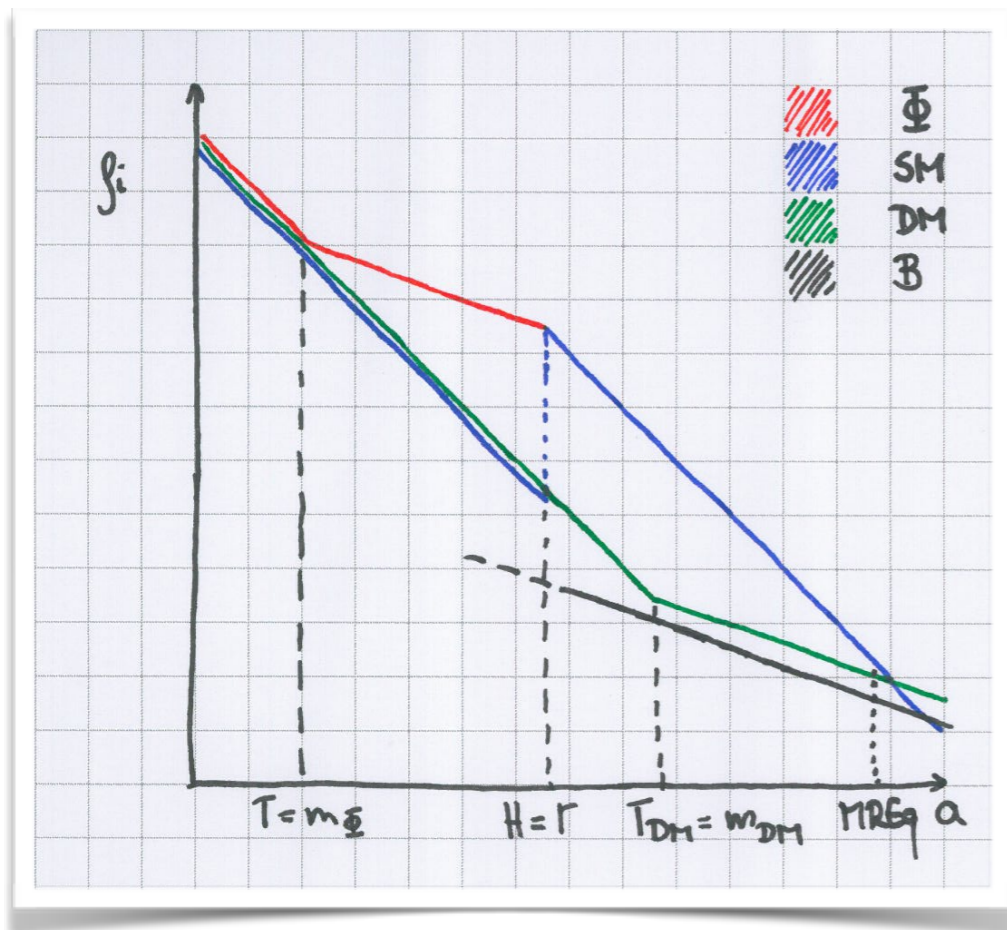
Bonus Features

1. Model Building
2. Baryogenesis
3. Light fermionic DM and the core/cusp problem.

Relic Density of DM

- In order to set the right relic density we need to wait long enough, this sets the width of Φ .

$$\Gamma \simeq \frac{m_\Phi^2}{M_{Pl}} \left(\Delta \frac{\Omega_{DM}}{\Omega_B} \frac{m_B}{m_{DM}} \right)^2 \quad \Delta \frac{\Omega_{DM}}{\Omega_B} \frac{m_B}{m_{DM}} \sim \left. \frac{s_{DM}}{s_{SM}} \right|_\infty$$

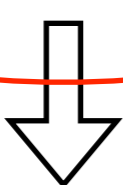


- On the other hand, we can not wait too long since this makes the reheat temperature too low.

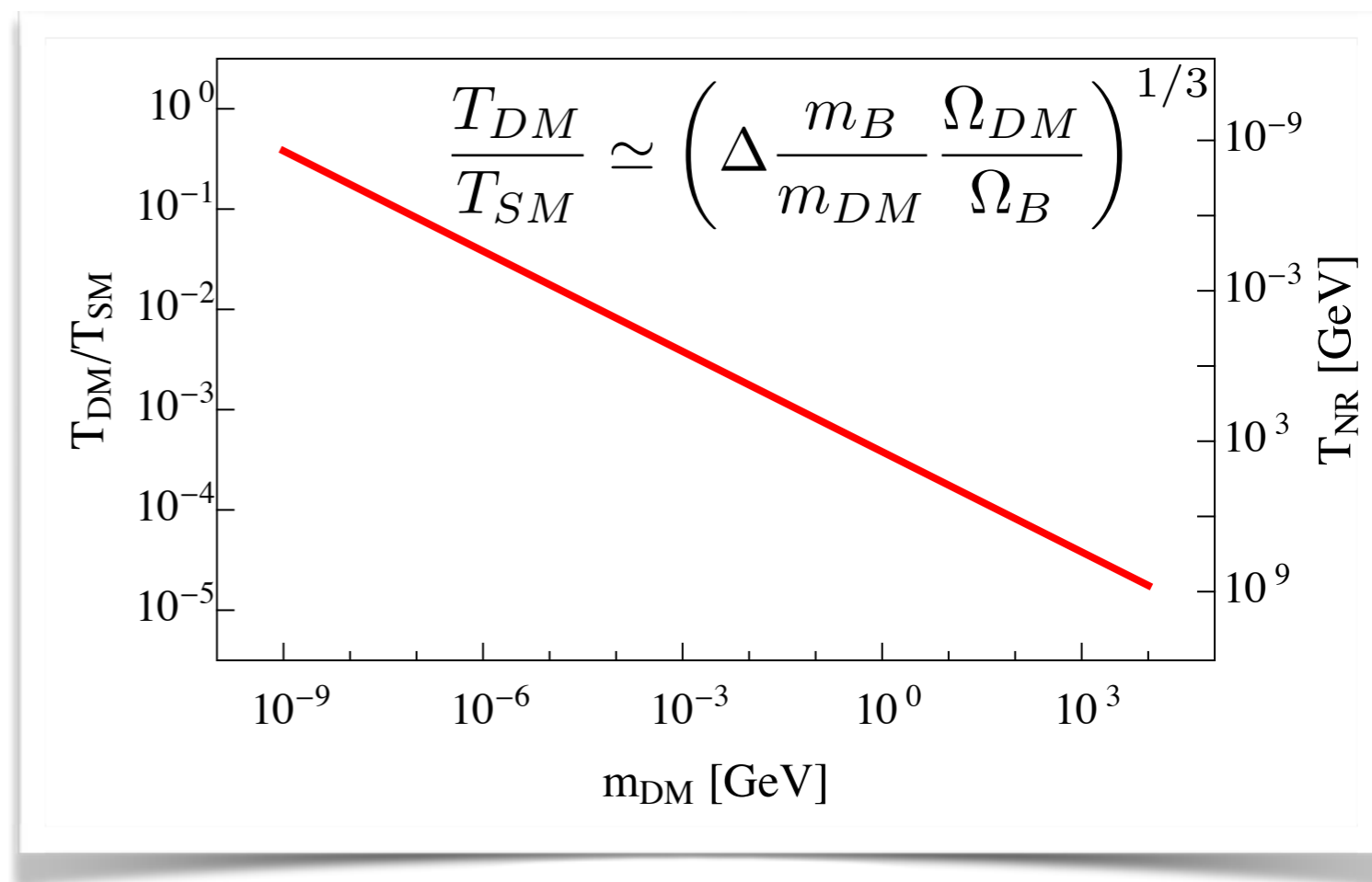
$$T_{RH} \simeq \sqrt{\Gamma M_{Pl}} = m_\Phi \Delta \frac{\Omega_{DM}}{\Omega_B} \frac{m_B}{m_{DM}}$$

How cold are the Dark Sectors?

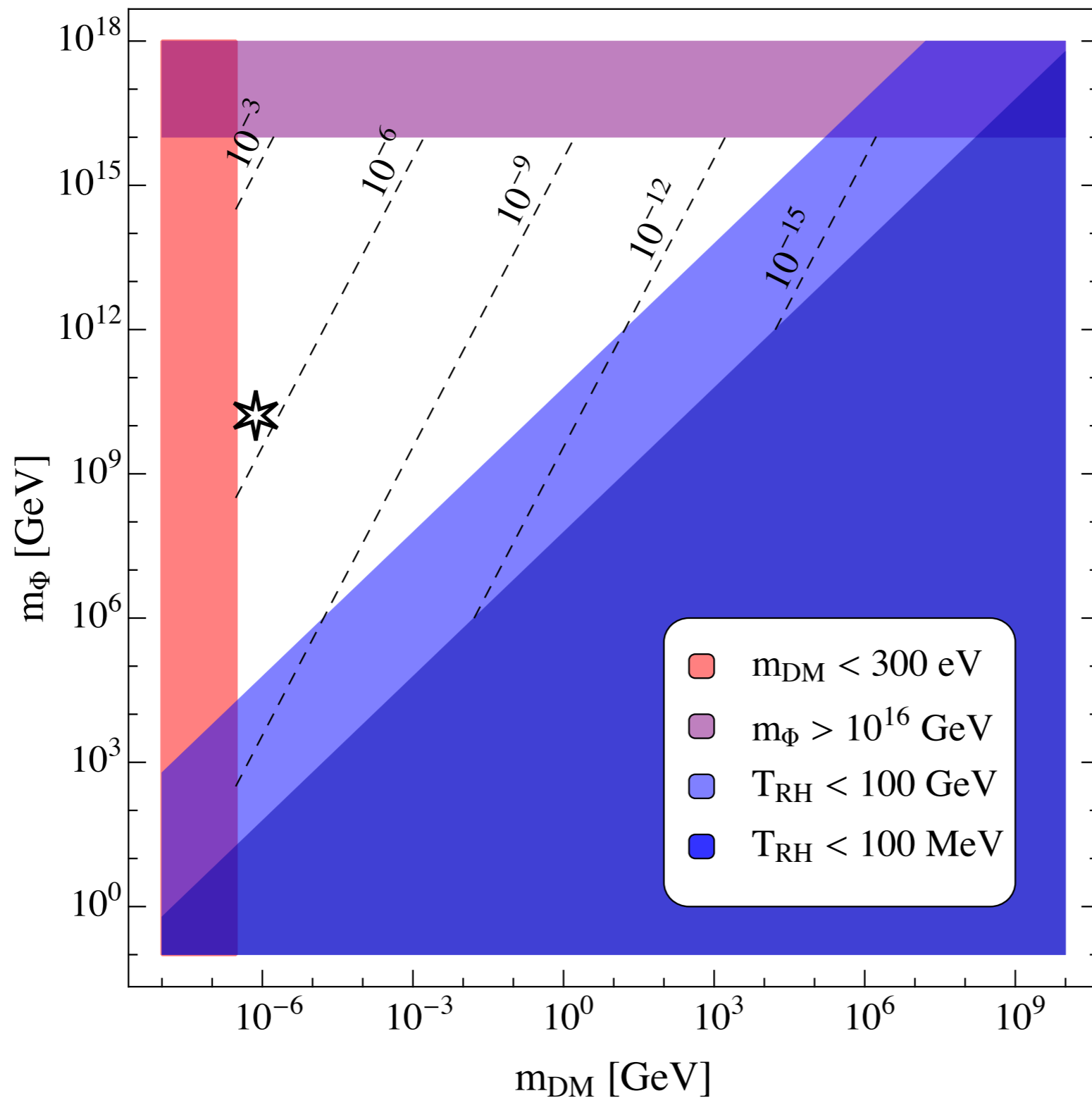
- Since the SM gets an energy injection from the decays of Φ , SM is hotter than all the other sectors.
- This relaxes the free-streaming bounds because the DM becomes non-relativistic earlier.

$$m_{\text{DM}} \gtrsim 4.5 \text{ keV}$$


$$m_{\text{DM}} \gtrsim 500 \text{ eV}$$



Parameter Space



$$\Gamma_\Phi = \frac{\kappa^2}{8\pi} m_\Phi$$

Simple example of UV completion?

- Introduce three right-handed neutrinos N_i , with masses around M and yukawa couplings identical to the lepton up-sector.
- Satisfying the known Δm_{ij}^2 's gives us:

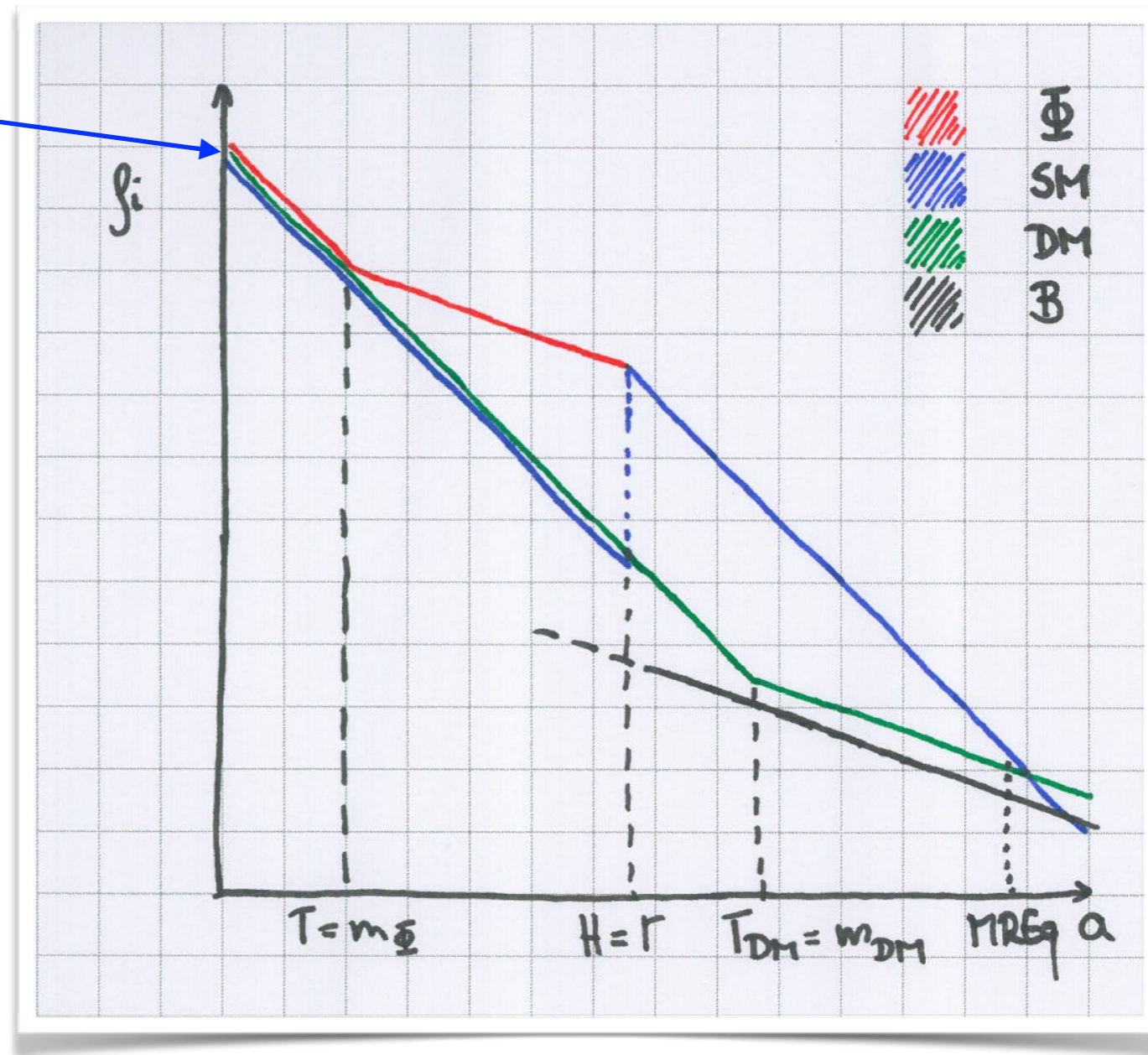
$$M \sim 10^{10} \text{ GeV}$$

- The longest lived right-handed neutrino reheats the standard model and plays the role of Φ .
- In some sense the most “special” or “baroque” model is bound to dominate the entropy of the Universe.
- This gives the right decay constant:

$$\Gamma \sim \frac{y_e^2 M_N}{8\pi} \sim 10^{-3} \text{ GeV}$$

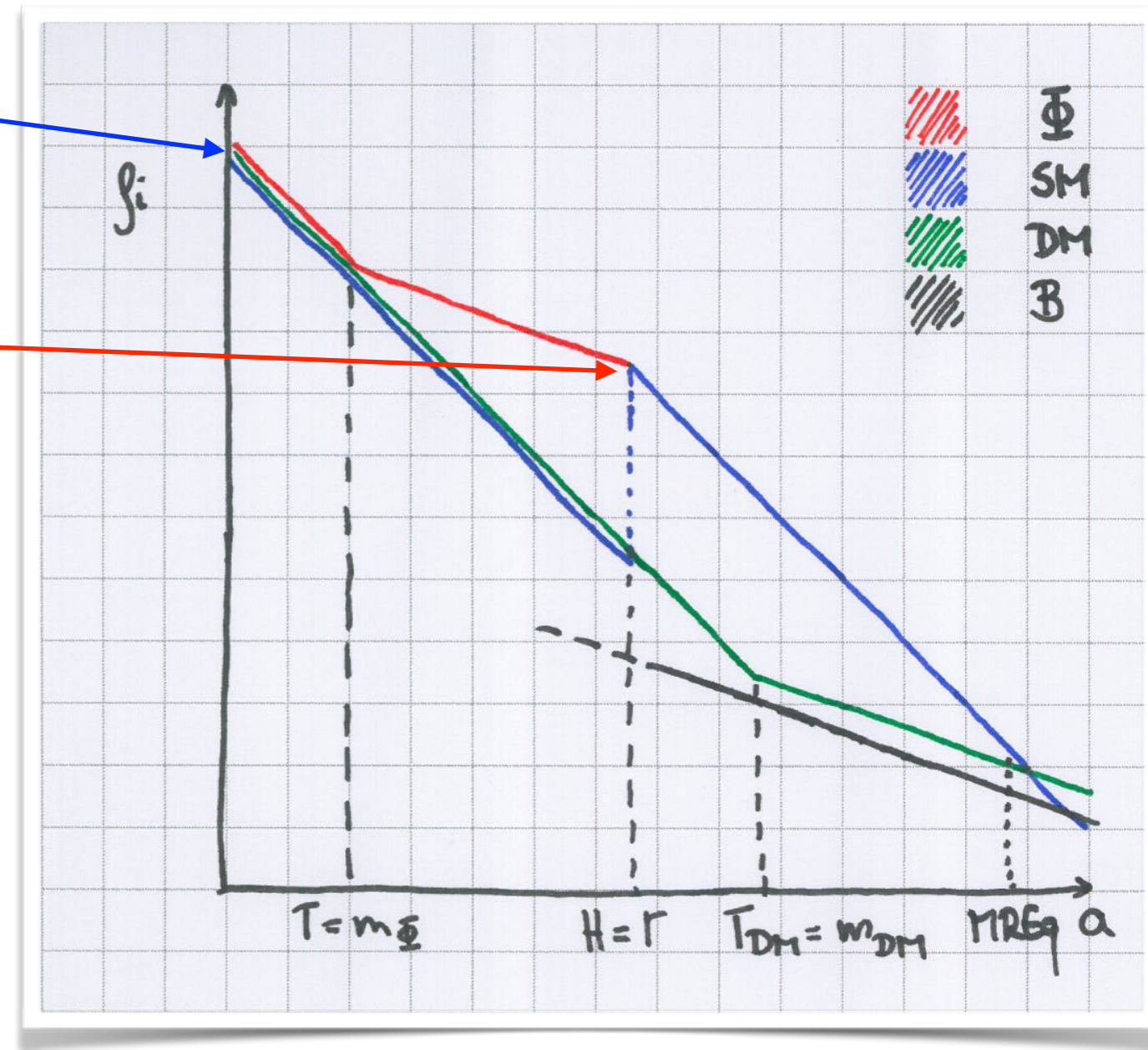
Baryogenesis

- A. The asymmetry is generated in primordial populations of baryons and/or dark matter



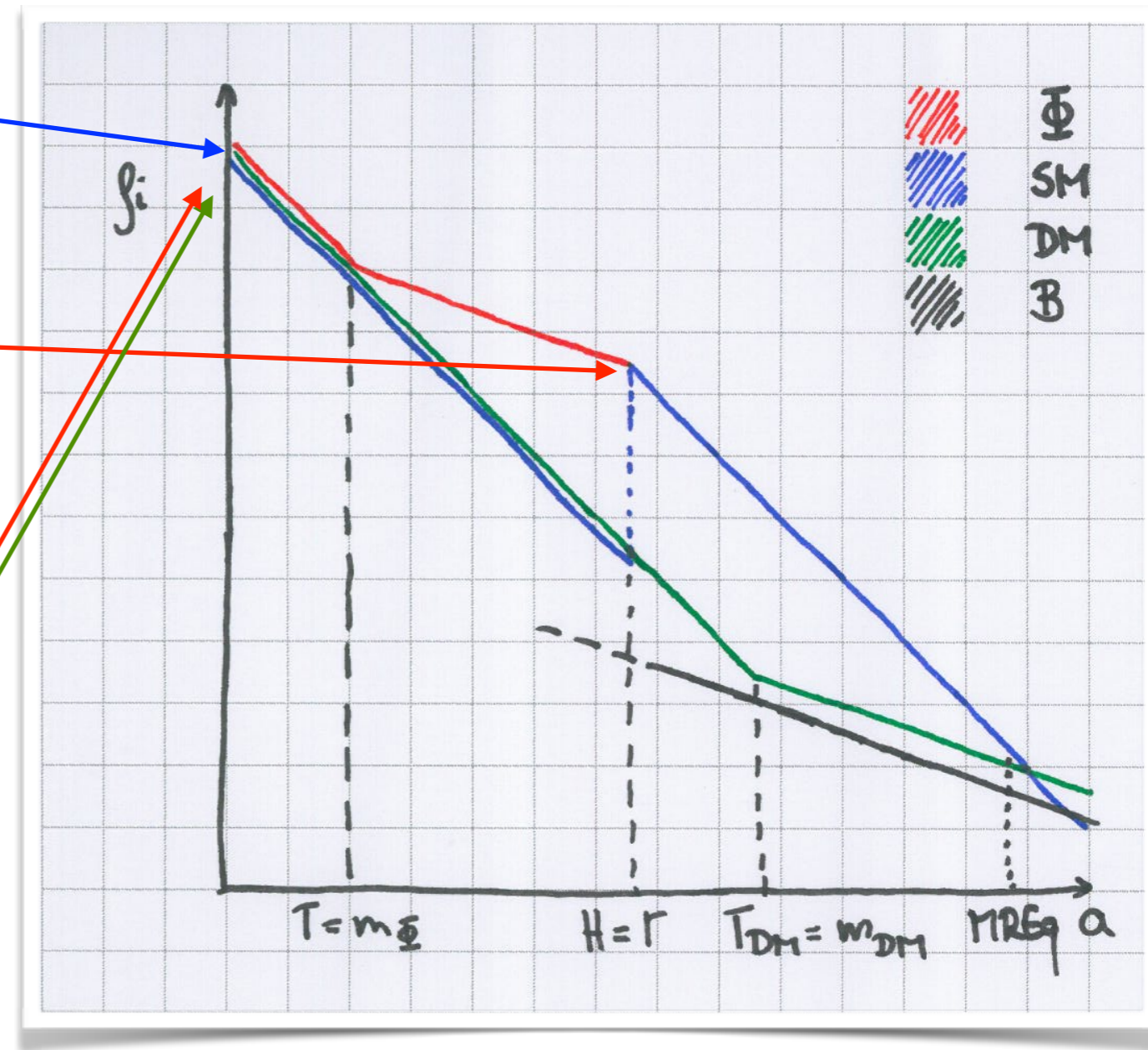
Baryogenesis

- A. The asymmetry is generated in primordial populations of baryons and/or dark matter
- B. The decays of Φ itself are asymmetric: We will show a RH neutrino case with a non-thermal leptogenesis scenario.



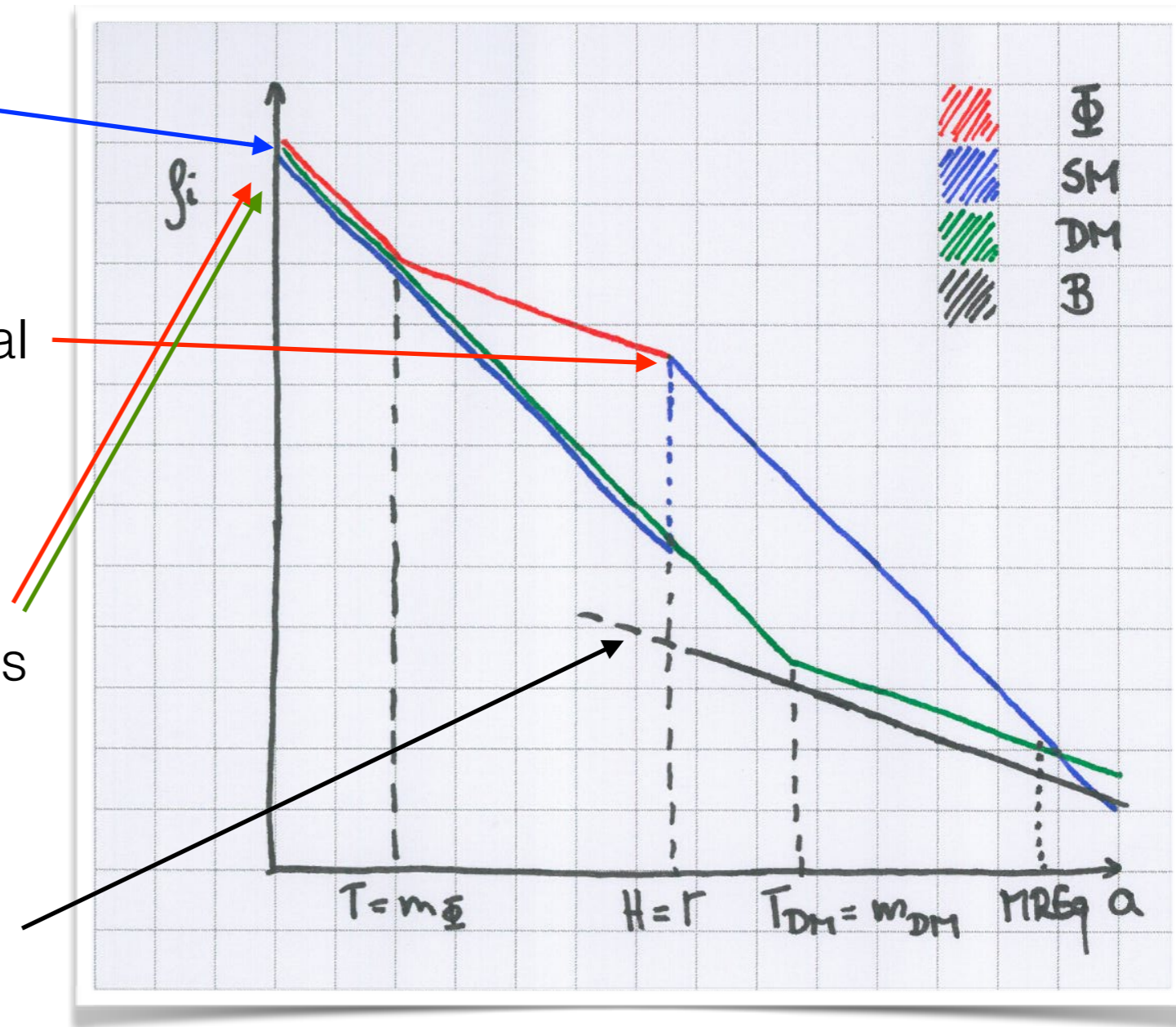
Baryogenesis

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- B. The decays of Φ itself are asymmetric: We will show a RH neutrino case with a non-thermal leptogenesis scenario.
- C. There are two Φ 's. One decays into visible sector one into dark sector. When the inflaton reheats the Φ 's it generates an asymmetry in both sectors.



Baryogenesis

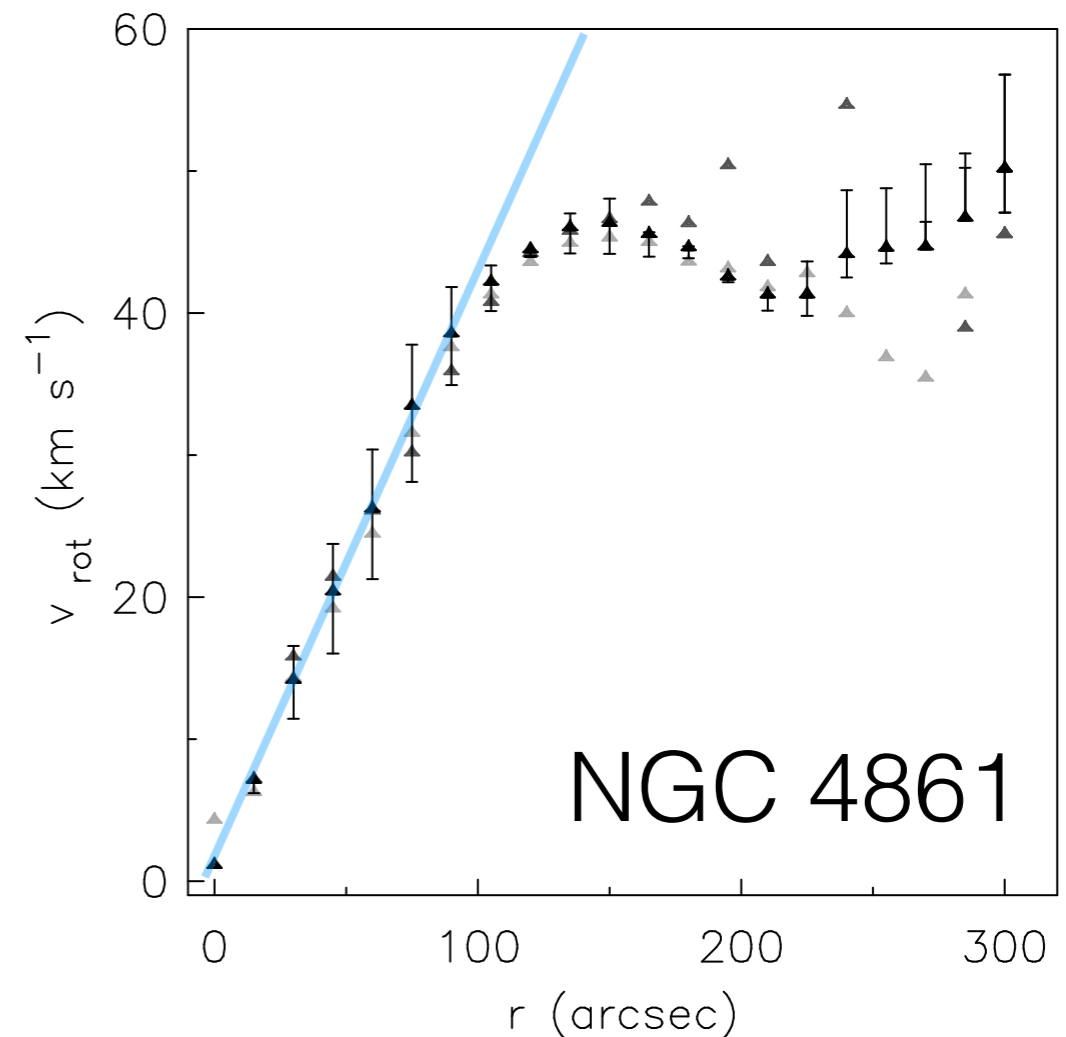
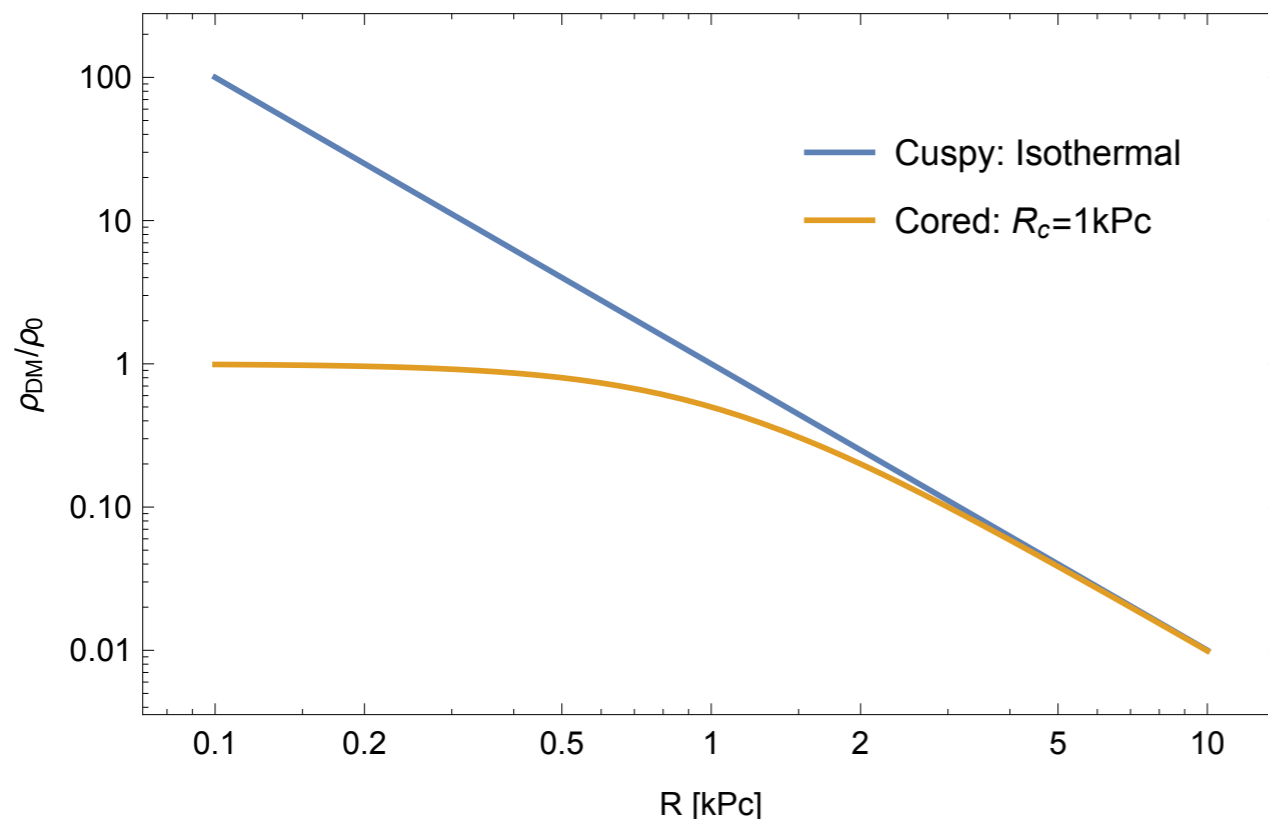
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- D. Standard Baryogenesis: Baryogenesis happens late in the visible sector.



Core/Cusp and Fermions

Core/Cusp problem

- Standard CDM simulations (without baryons) suggest a cuspy ($\sim 1/r$) density profile for galaxies [NFW].
- Current measurements indicate that those profiles are cored (~ 1) instead [0907.4635]



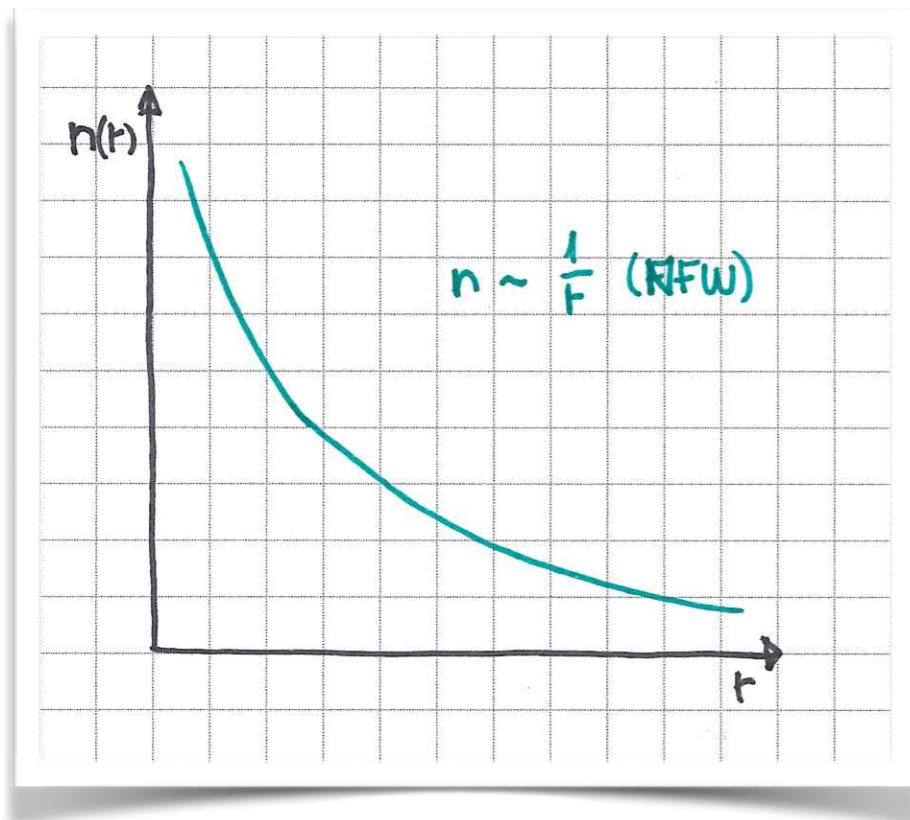
Core/Cusp problem I

- Domcke and Urbano [1409.3167], suggest a 200 eV fermion dark matter produces cores in dwarf galaxies.
- You could solve the equation of hydrostatic equilibrium — the solution is a polytrope with index $\gamma = 5/3$:

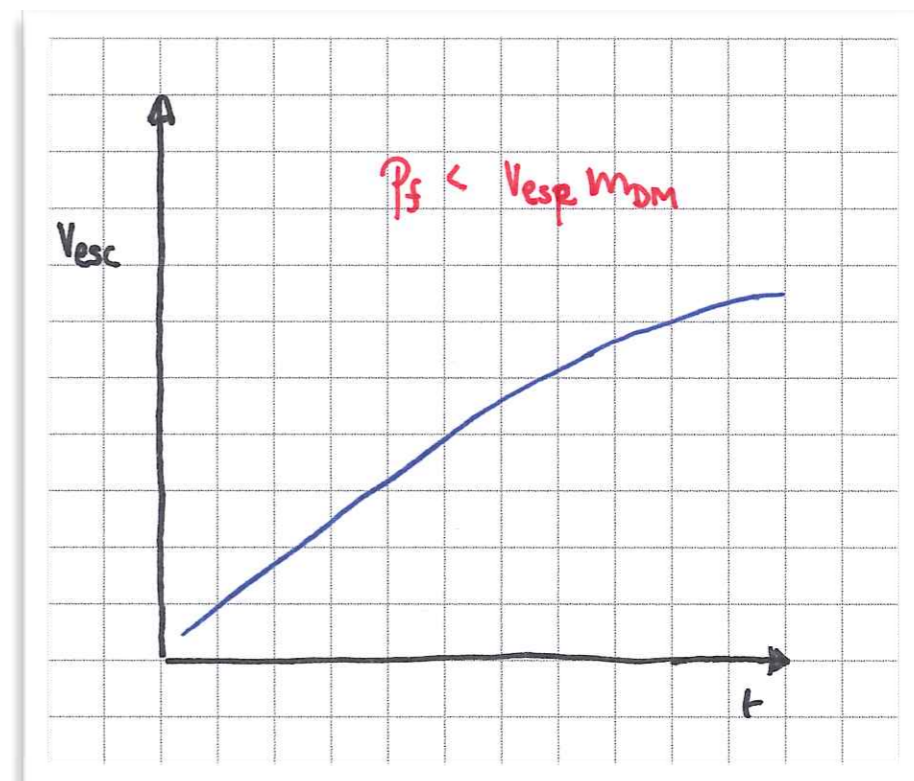
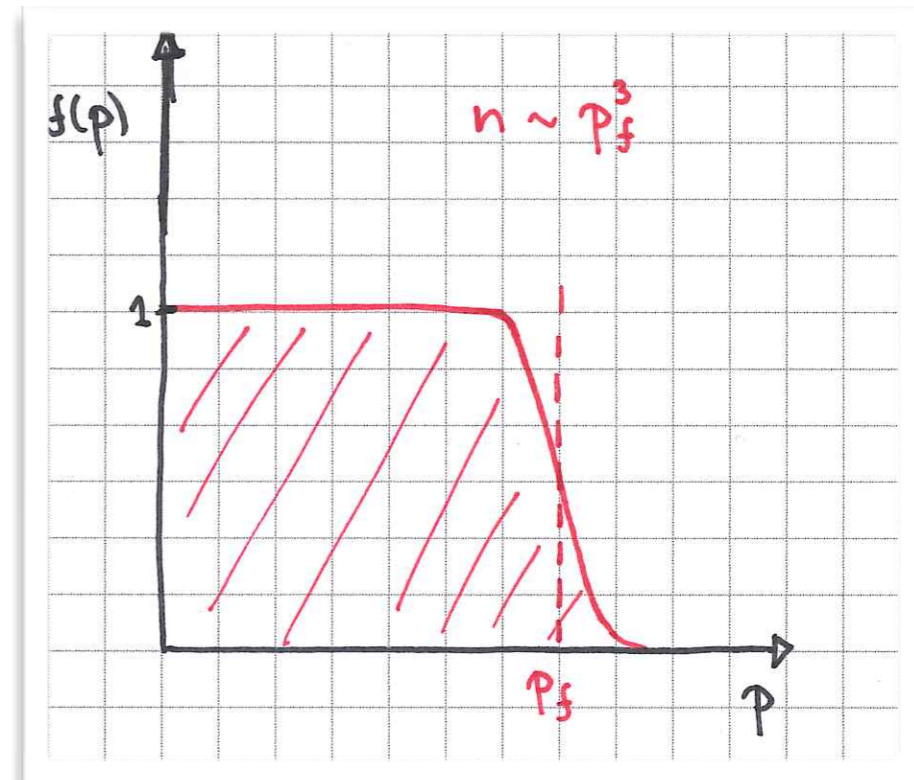
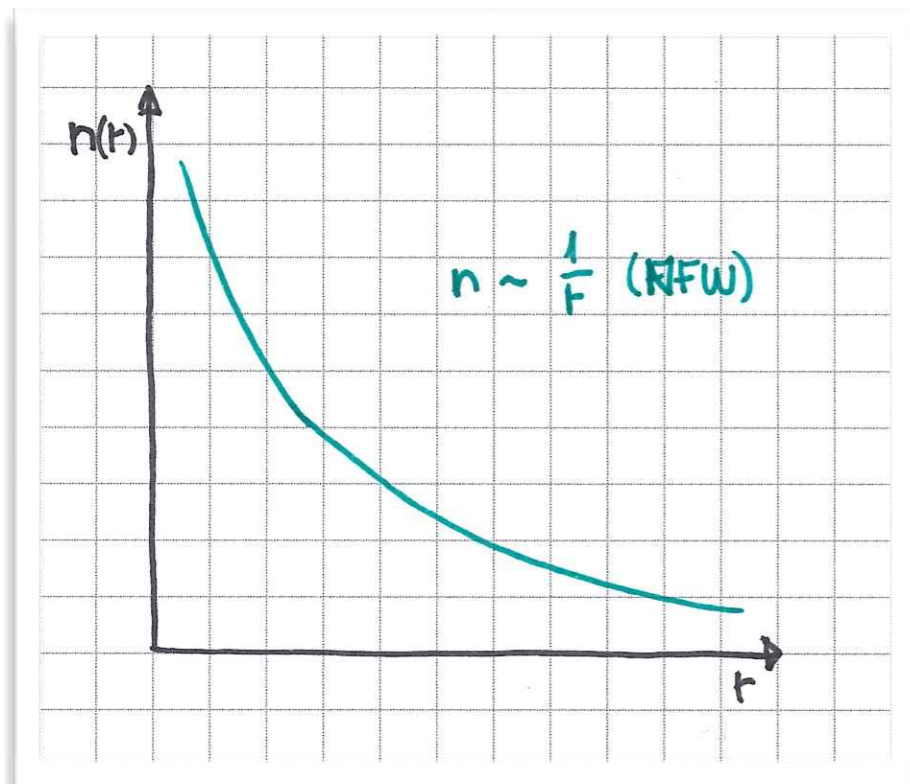
$$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2}$$
$$P = \frac{h^2}{5m_f^{8/3}} \left(\frac{3}{8\pi} \right)^{2/3} \rho^{5/3}$$

Core/Cusp problem

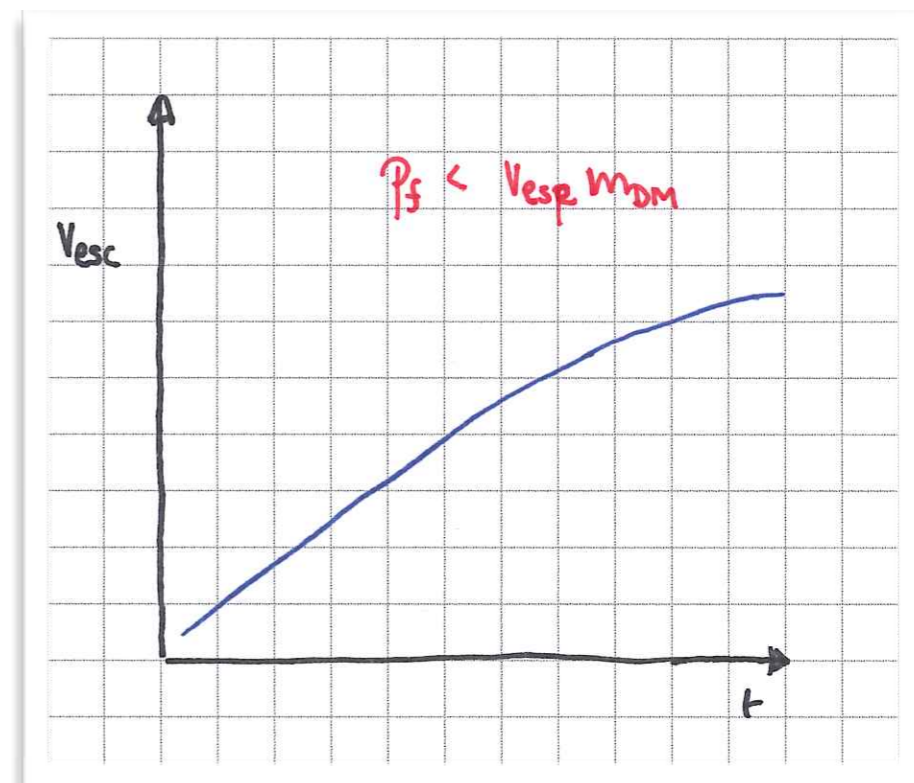
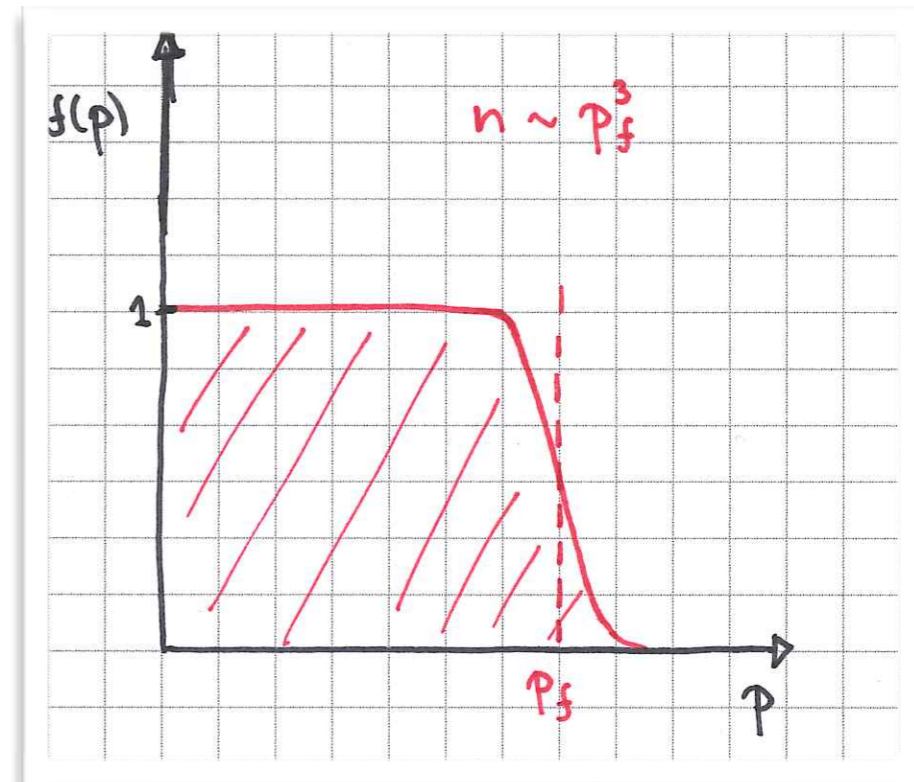
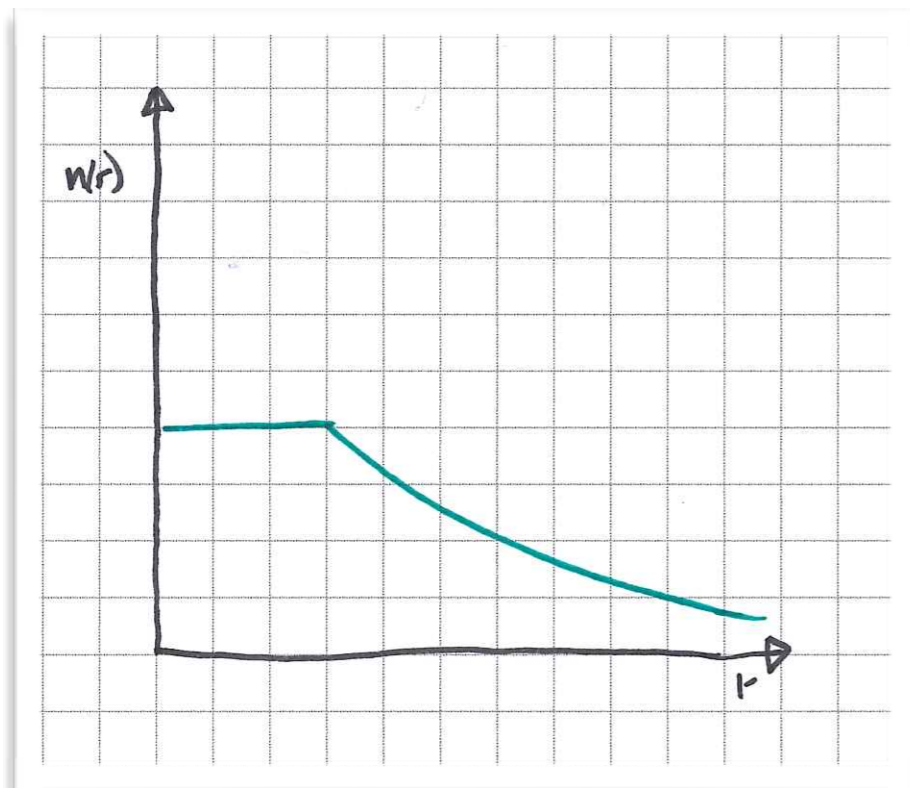
Assume a cuspy initial distribution



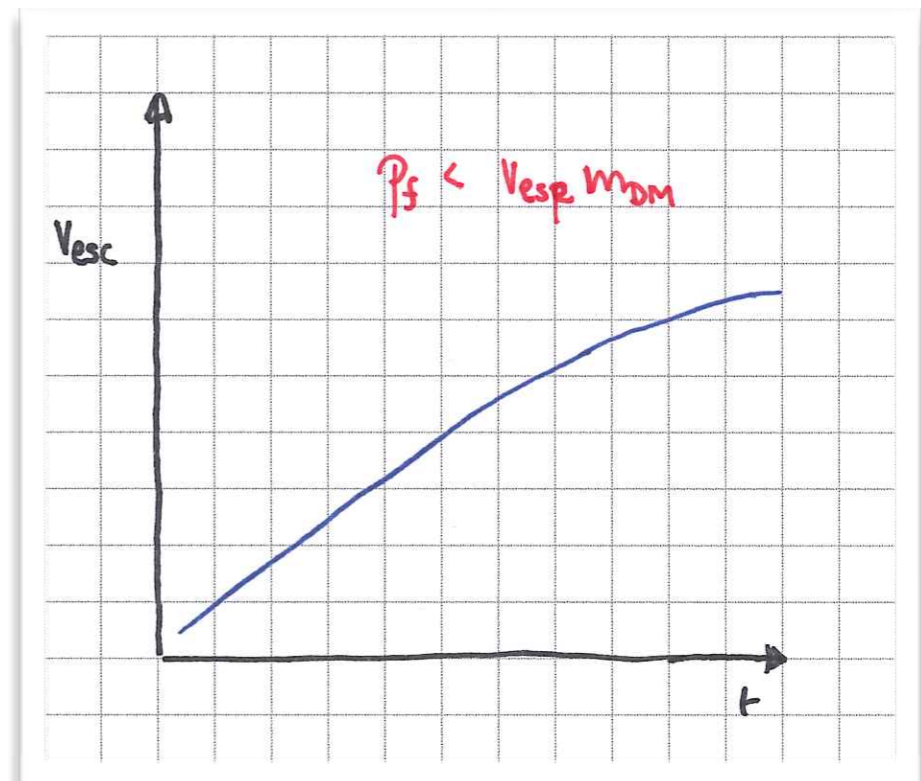
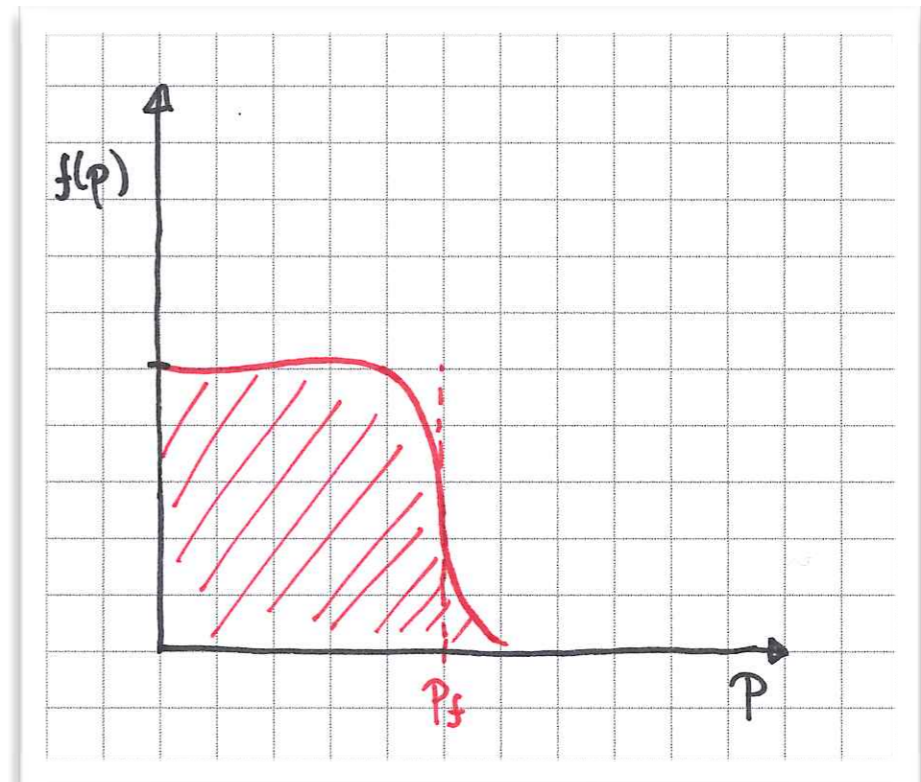
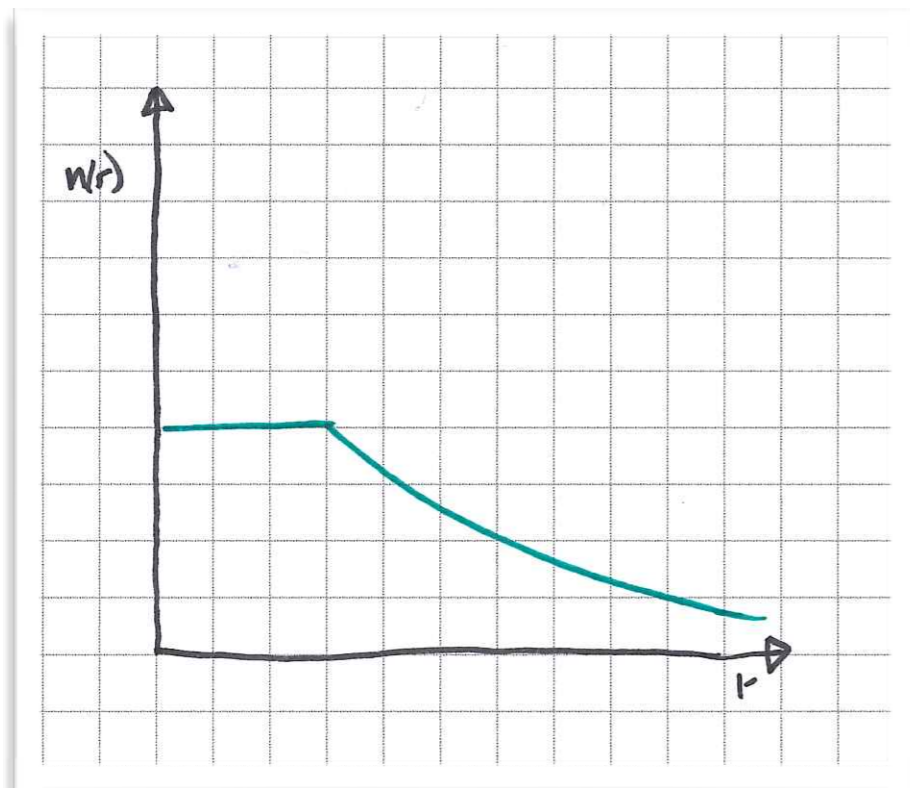
Core/Cusp problem



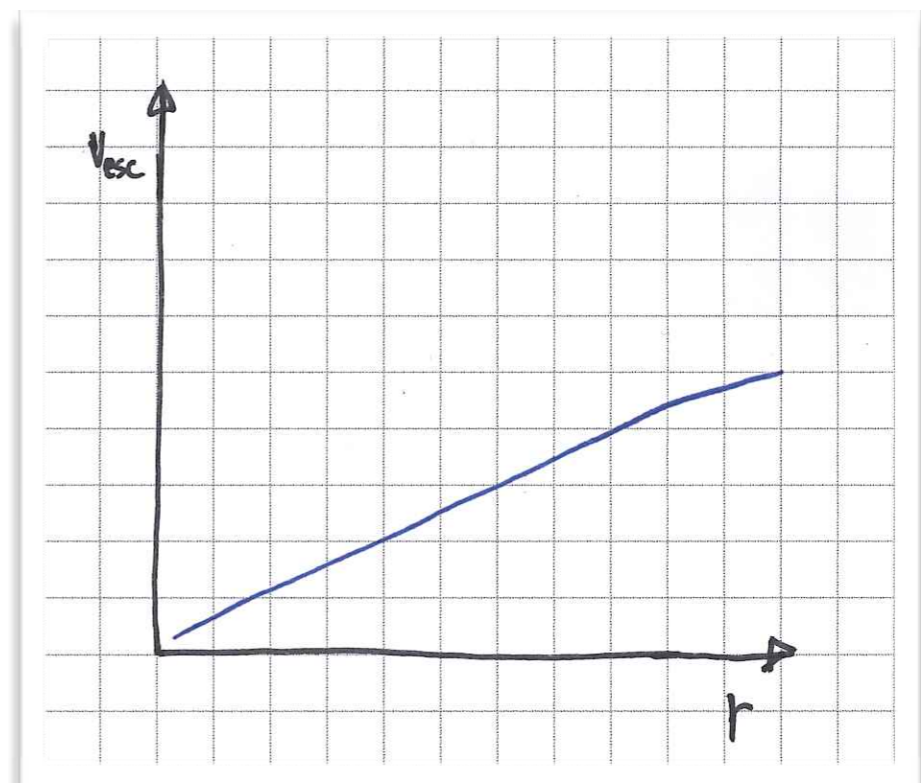
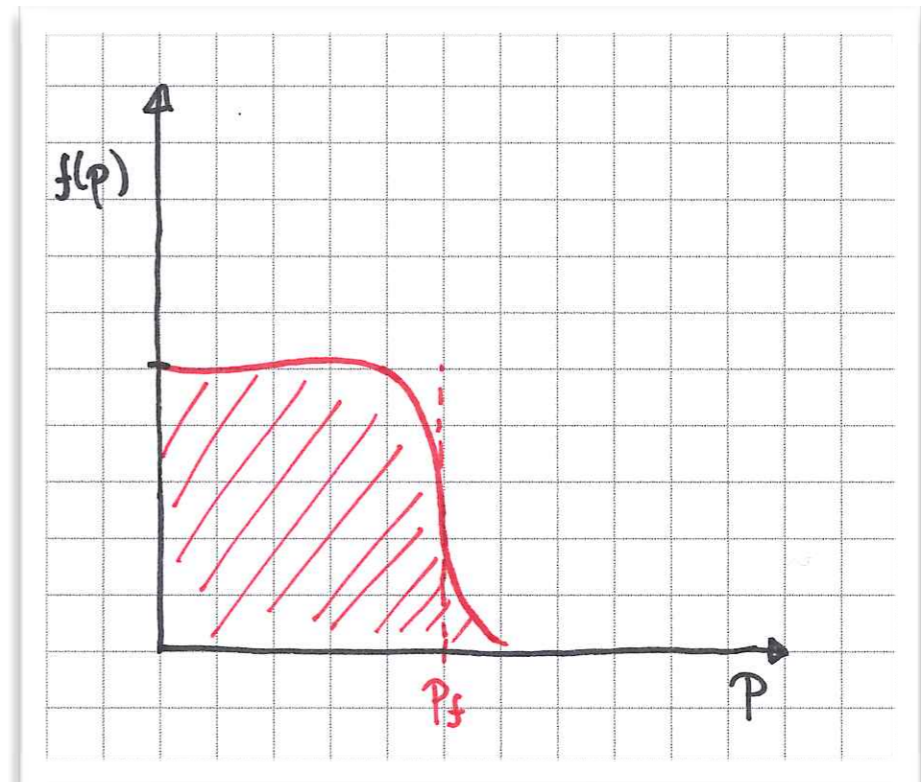
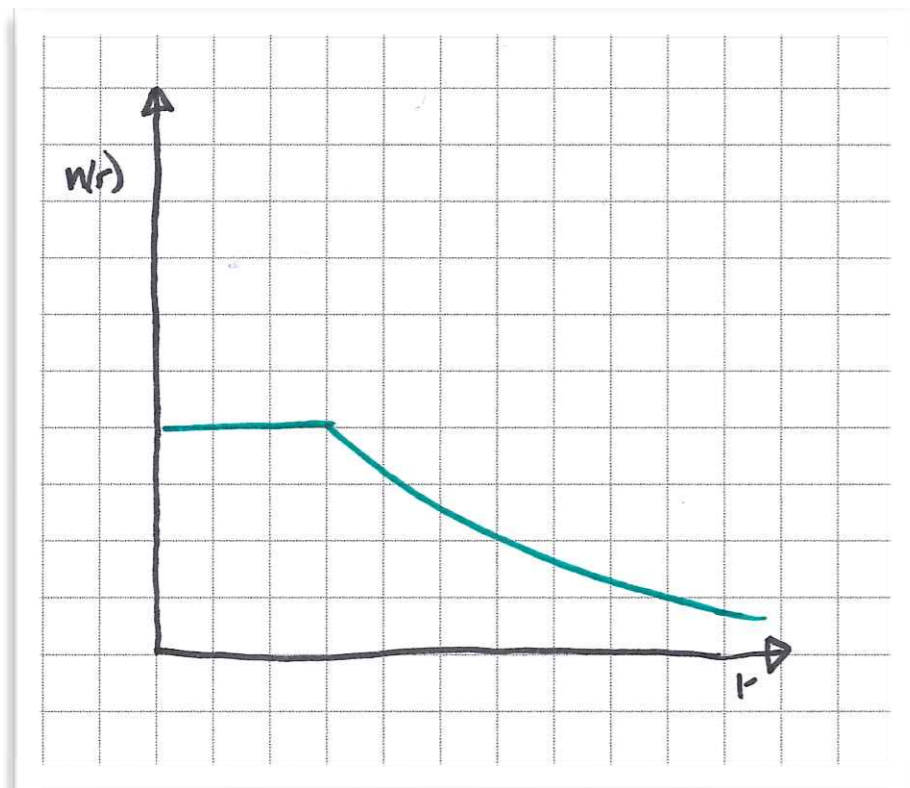
Core/Cusp problem



Core/Cusp problem

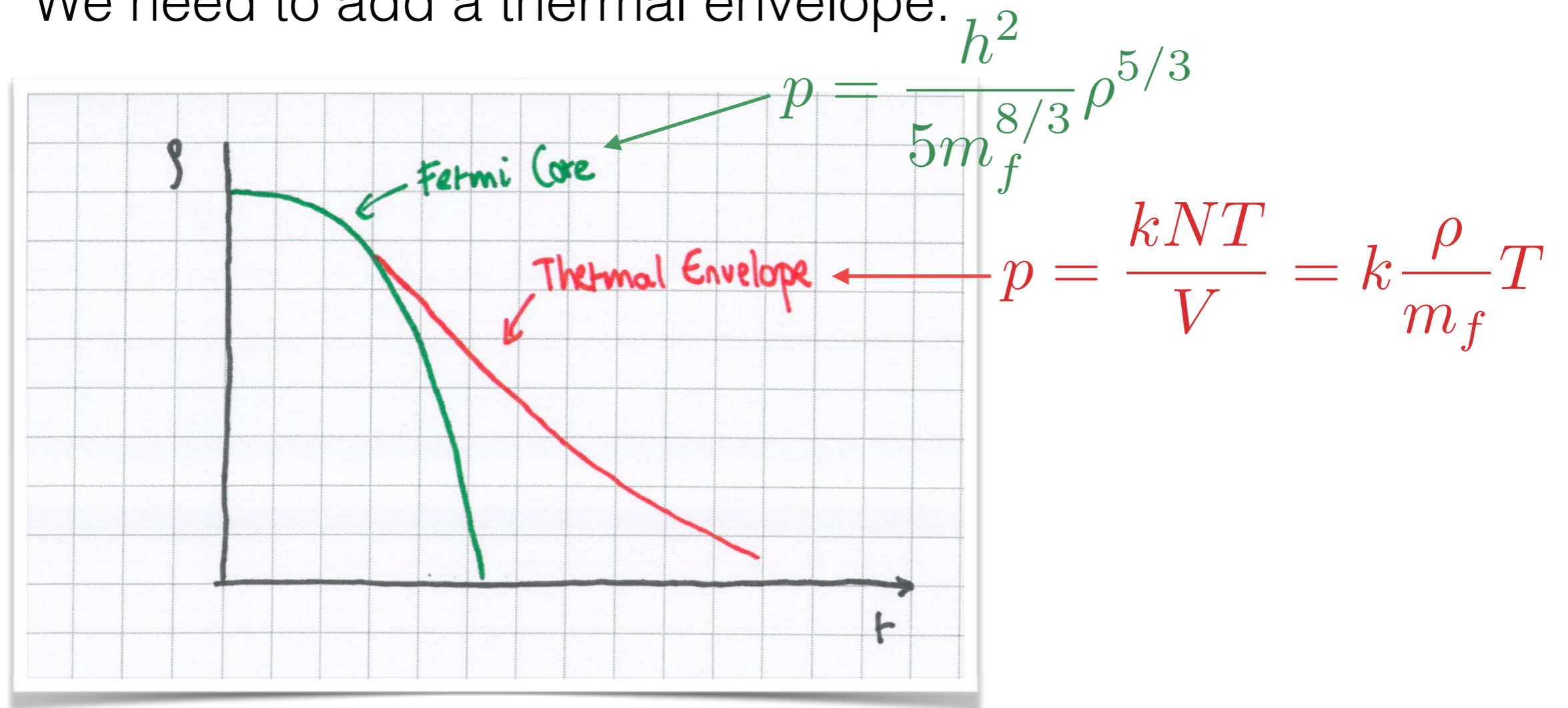


Core/Cusp problem

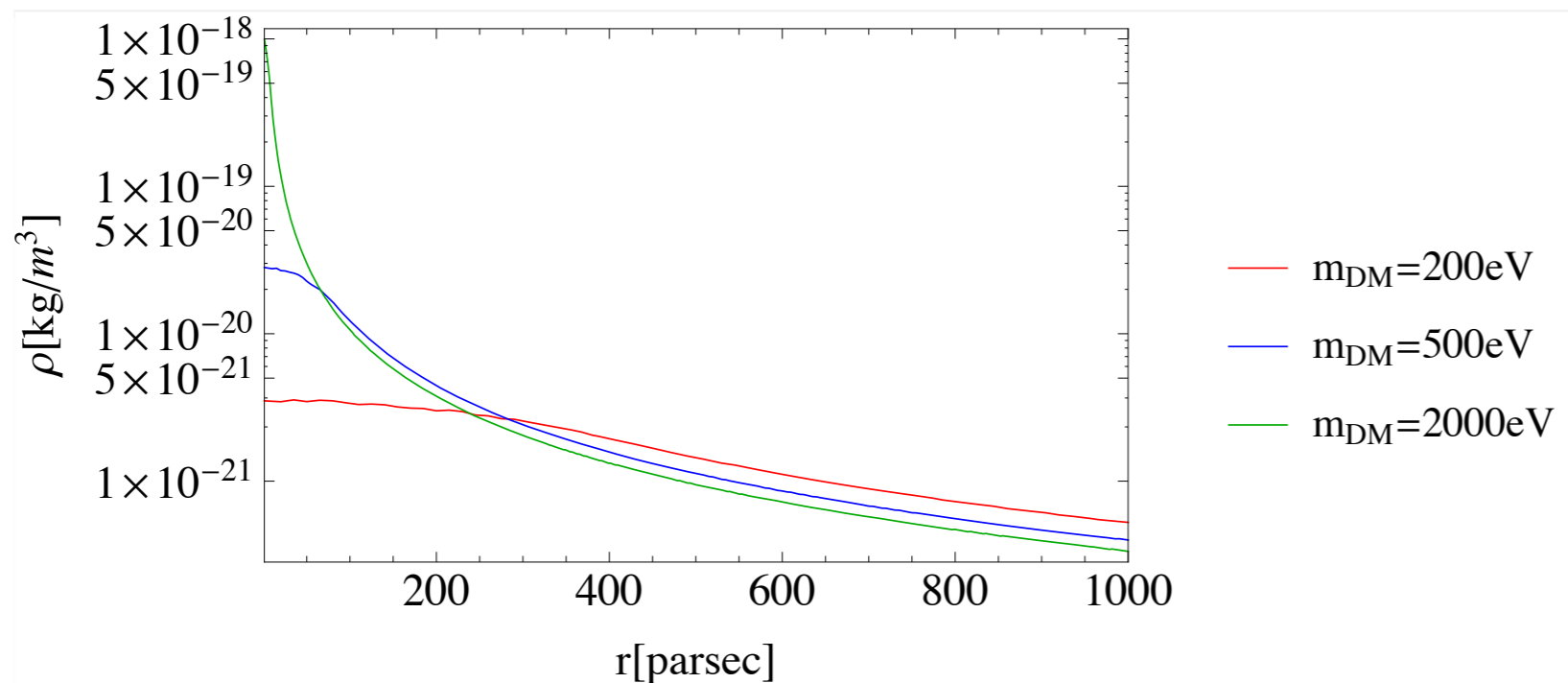


Core/Cusp problem II

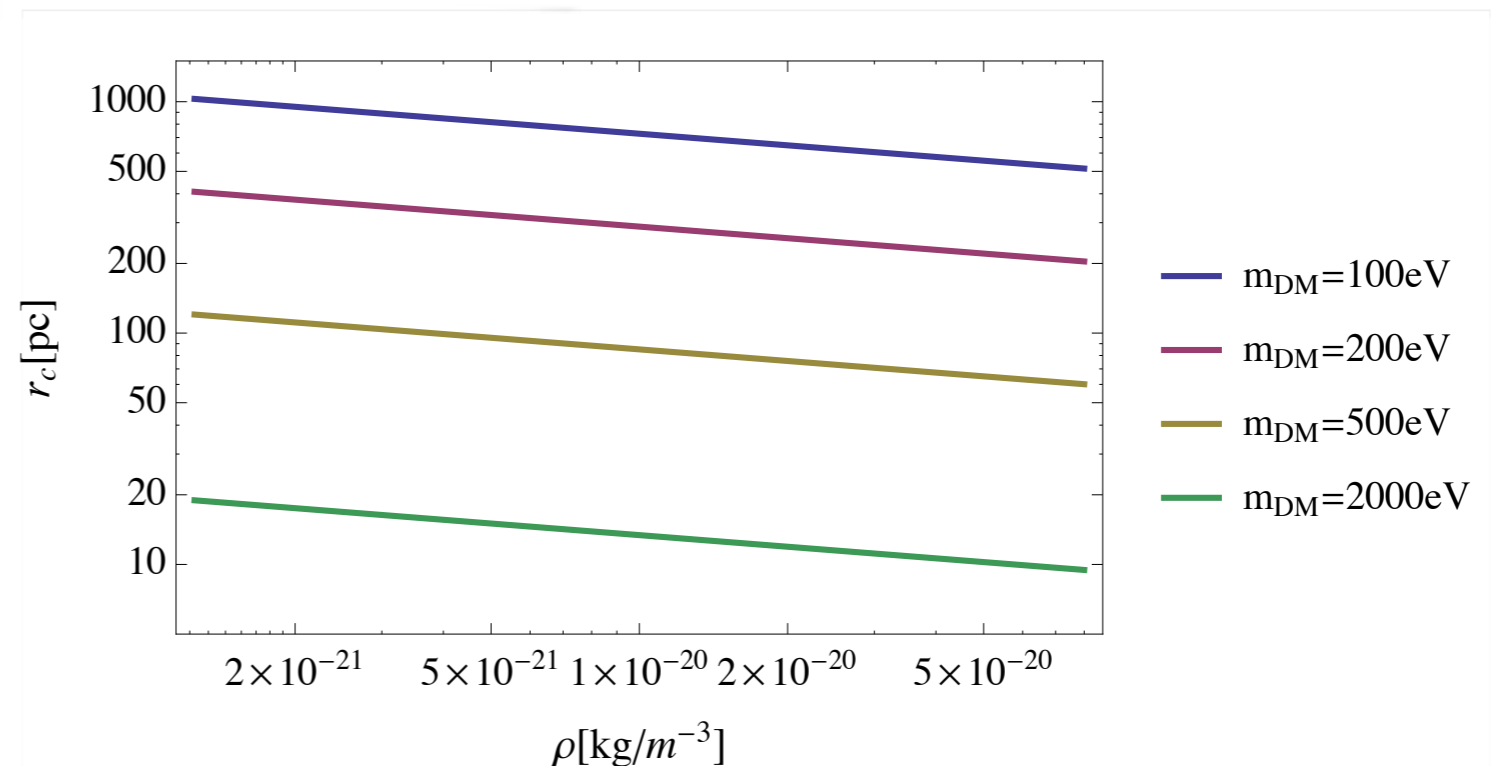
- At some point the assumption the gas is degenerate breaks down.
- We need to add a thermal envelope:

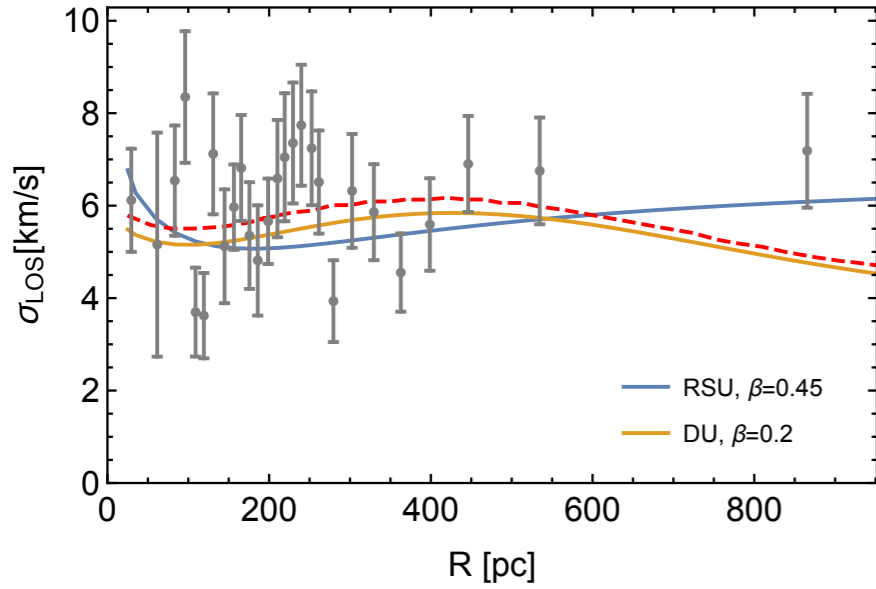
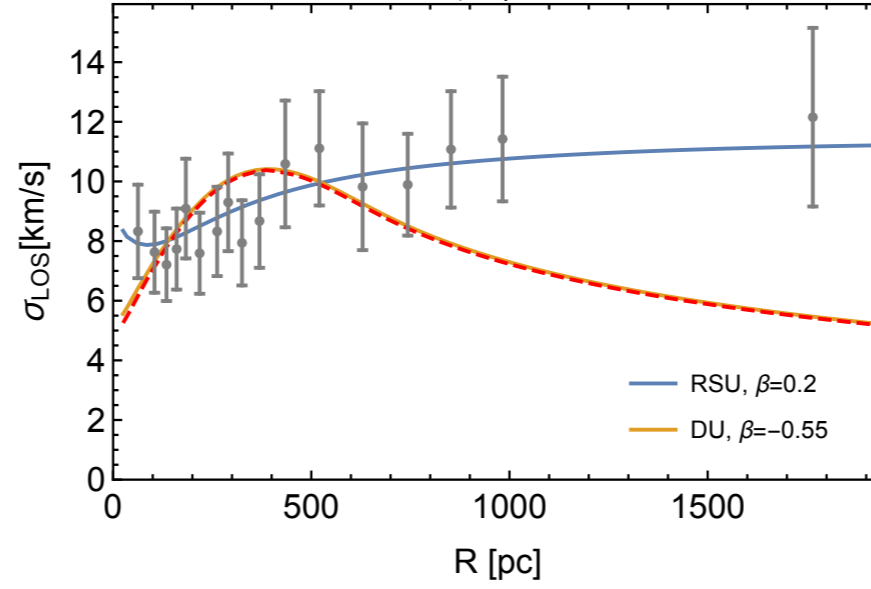
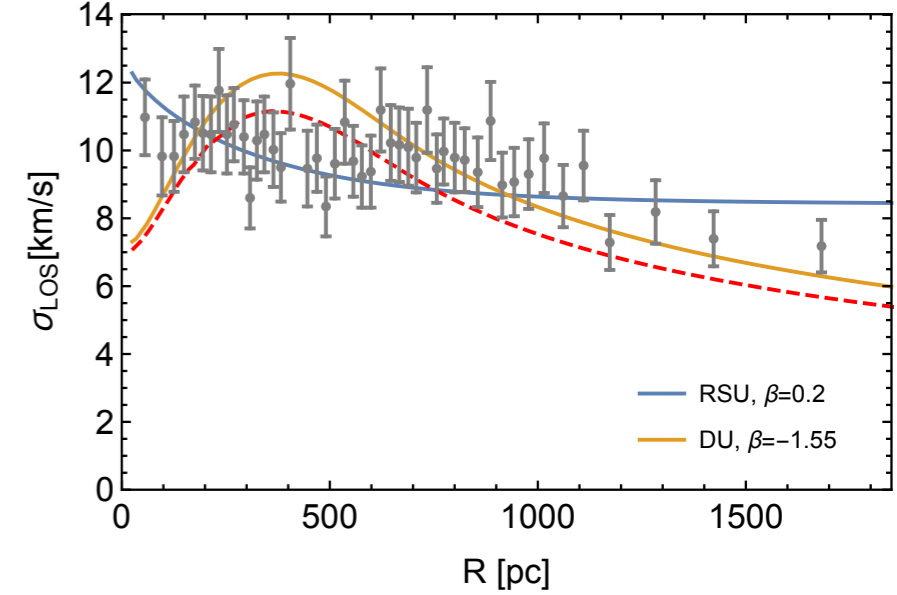
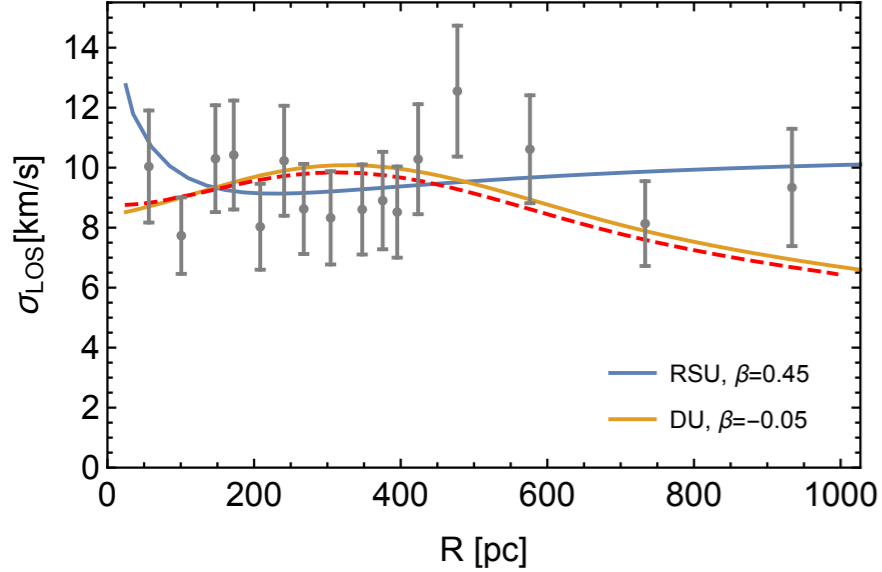
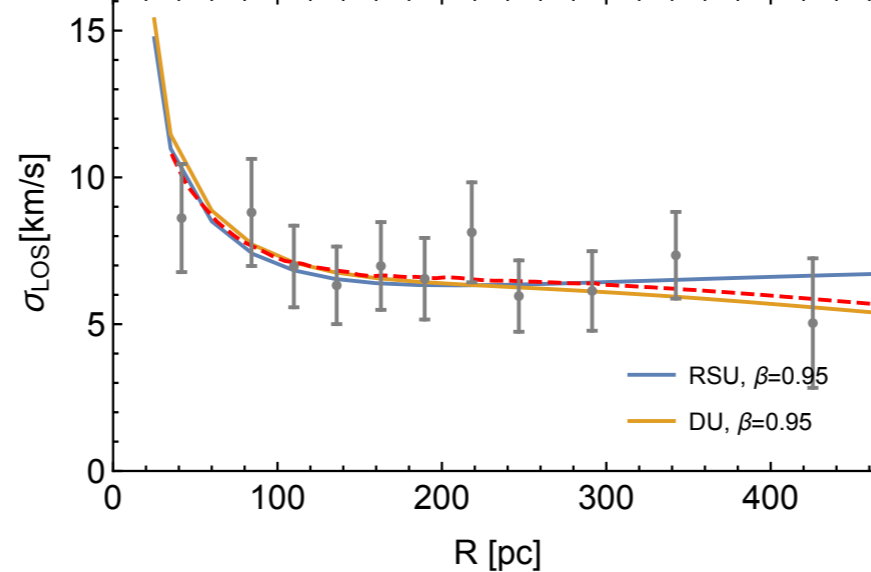
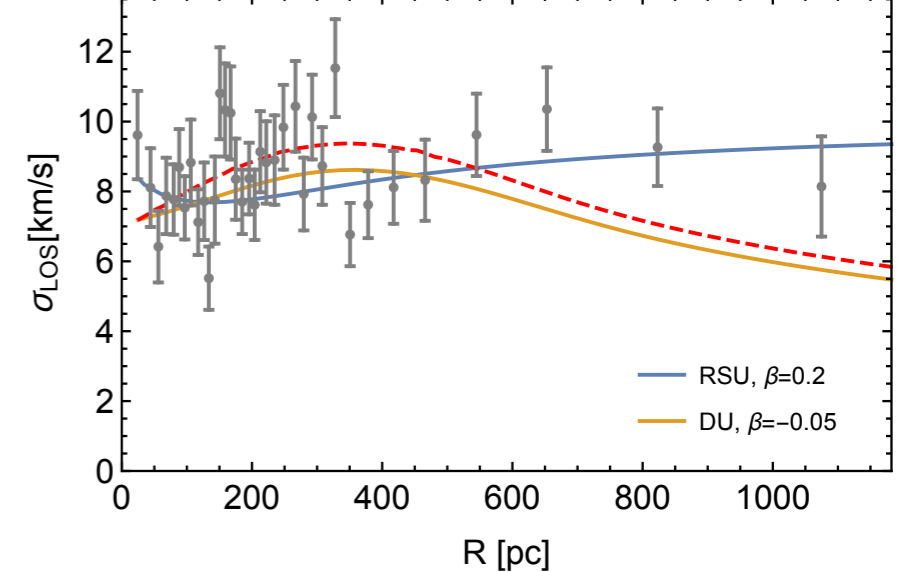
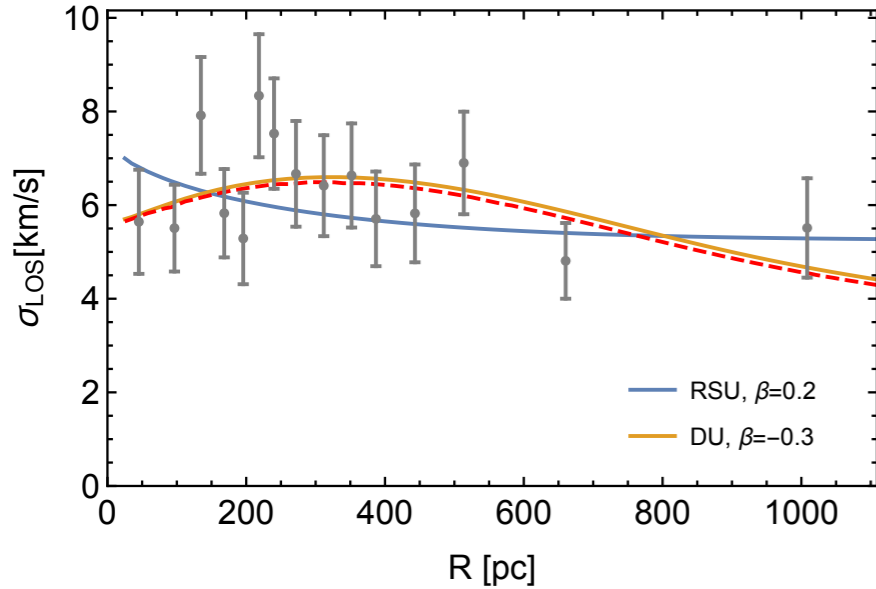
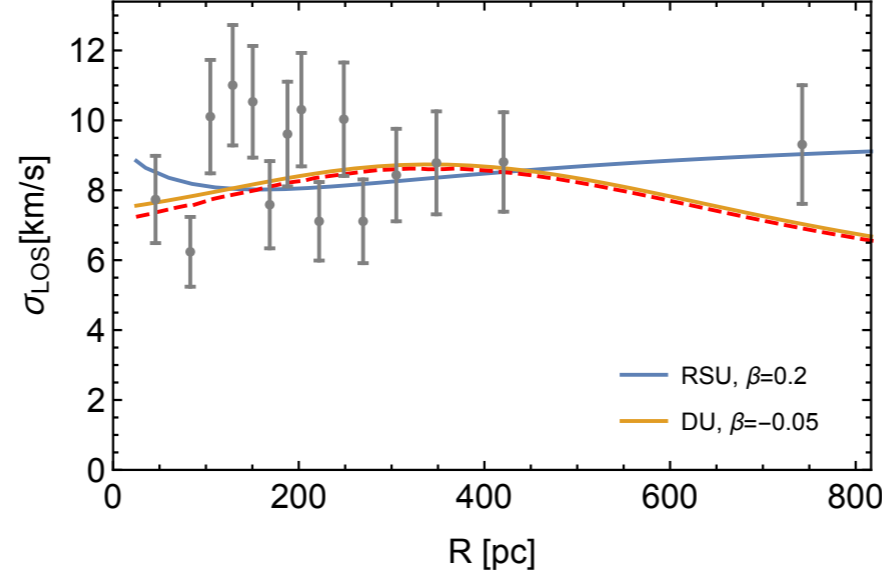


Core/Cusp: core radius

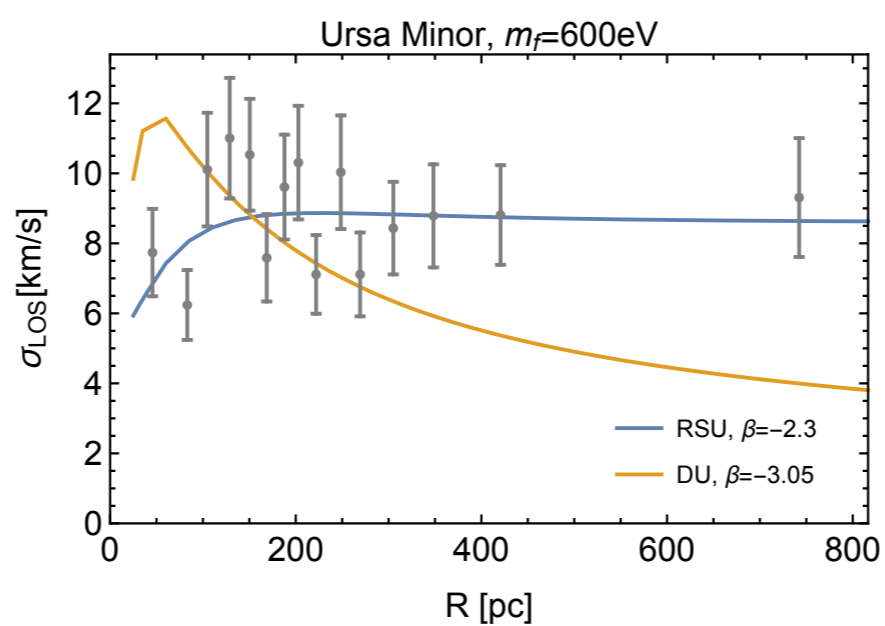
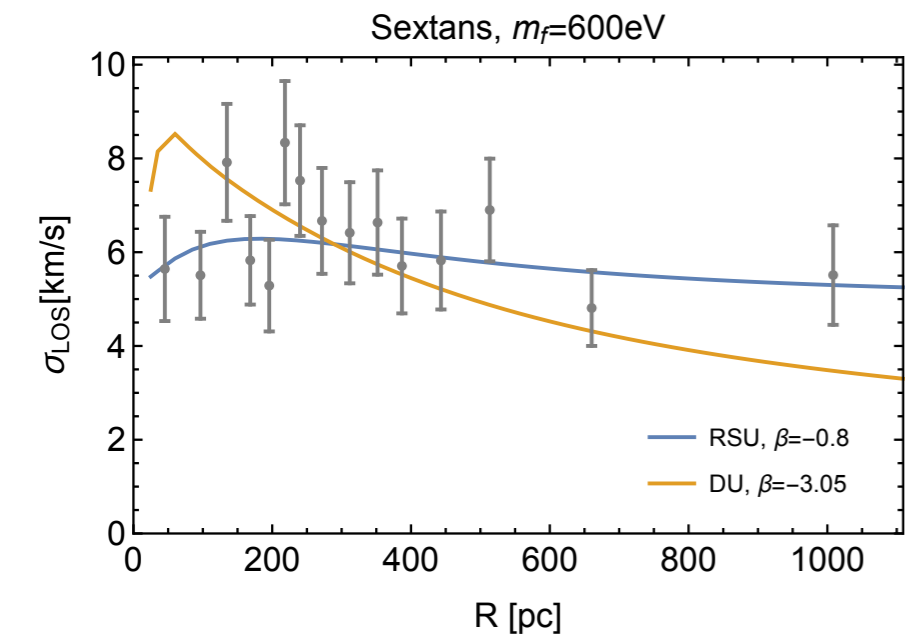
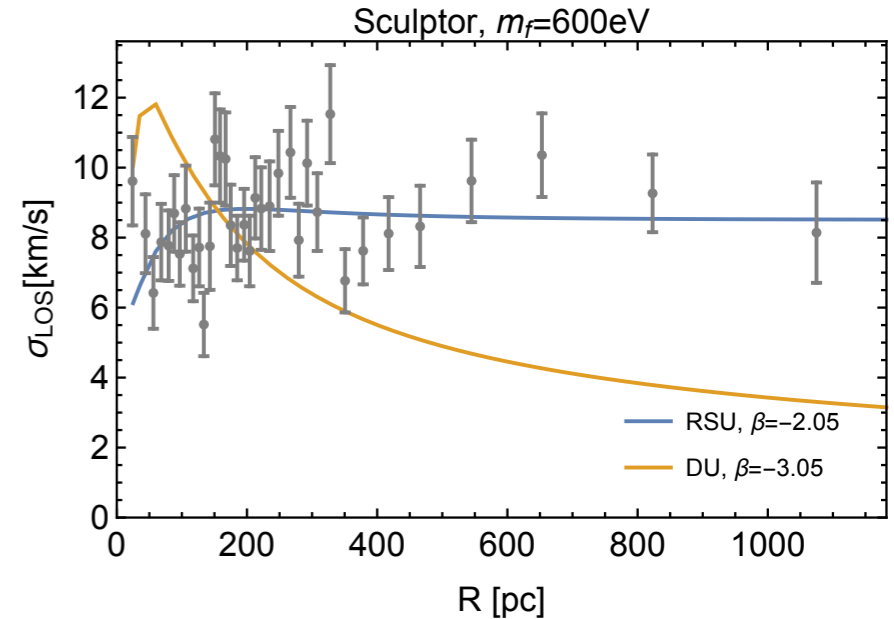
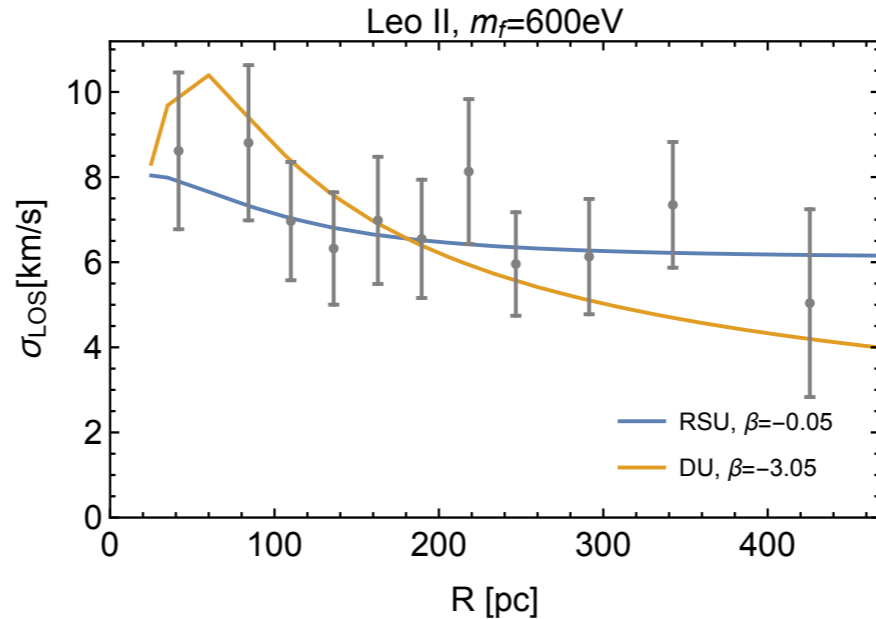
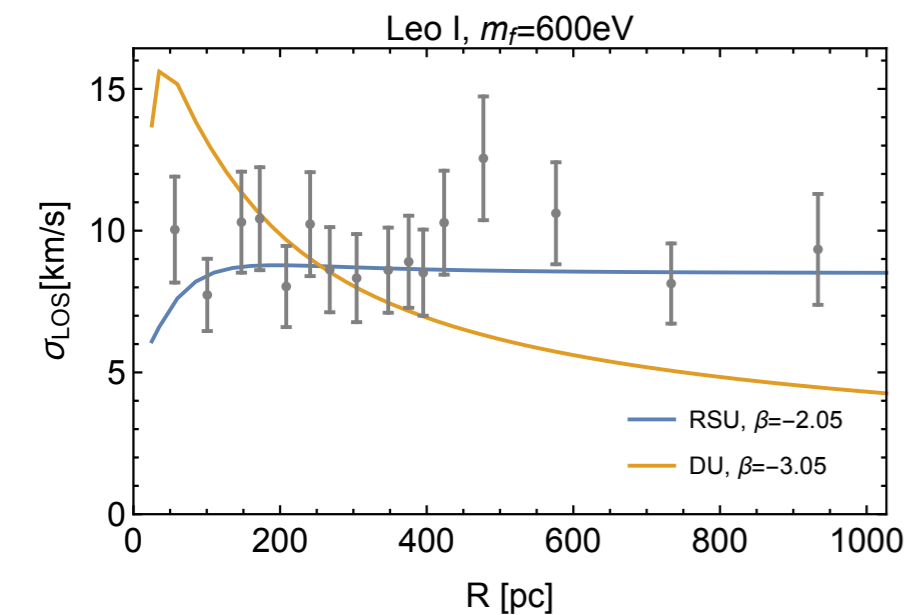
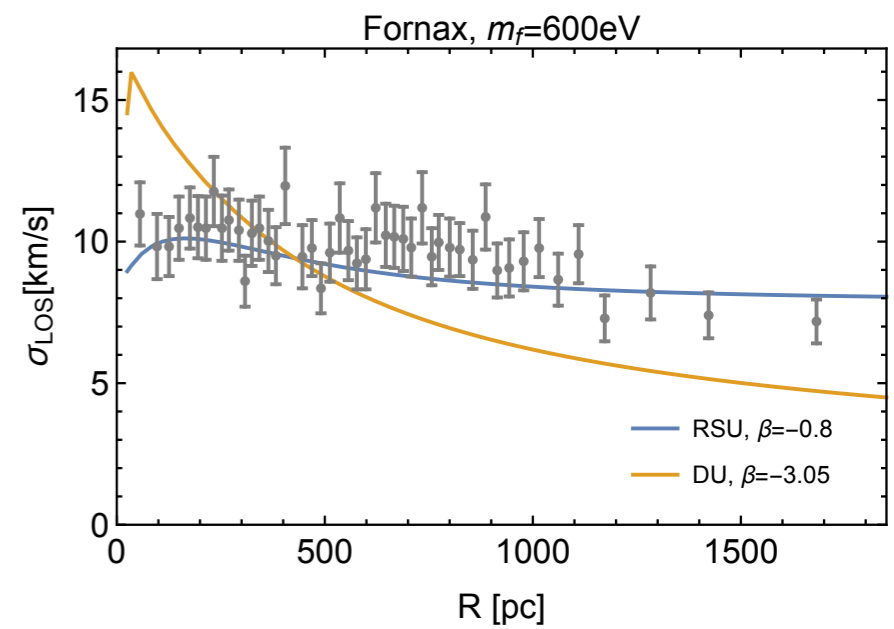
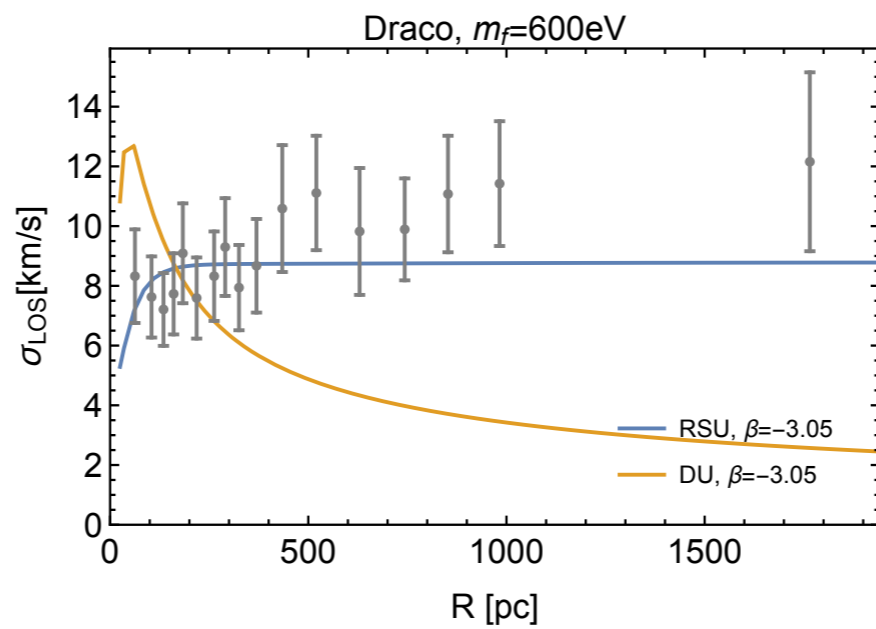
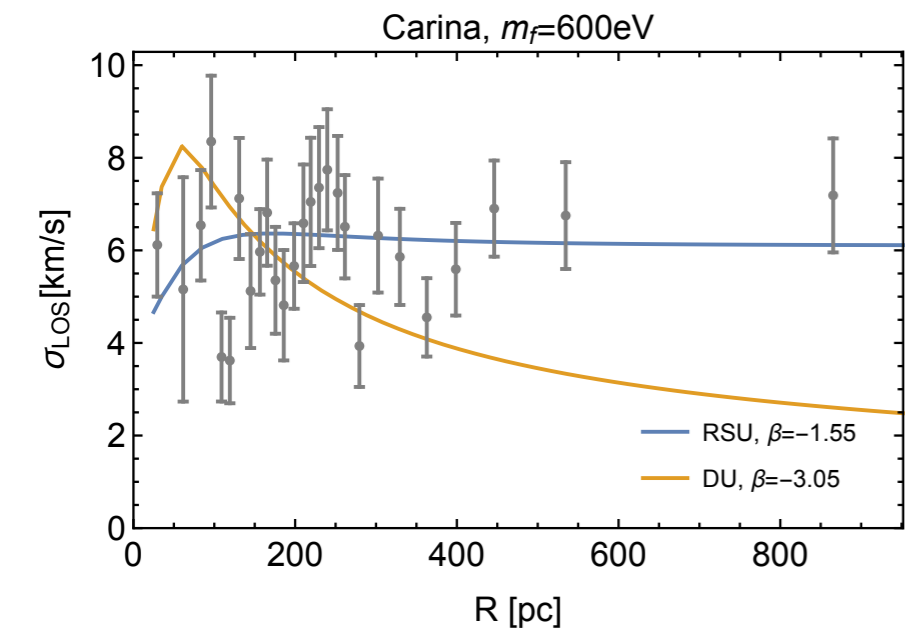


$$r_c = \left(\frac{\hbar^6}{G^3 m^8 \rho_0} \right)^{1/6}$$



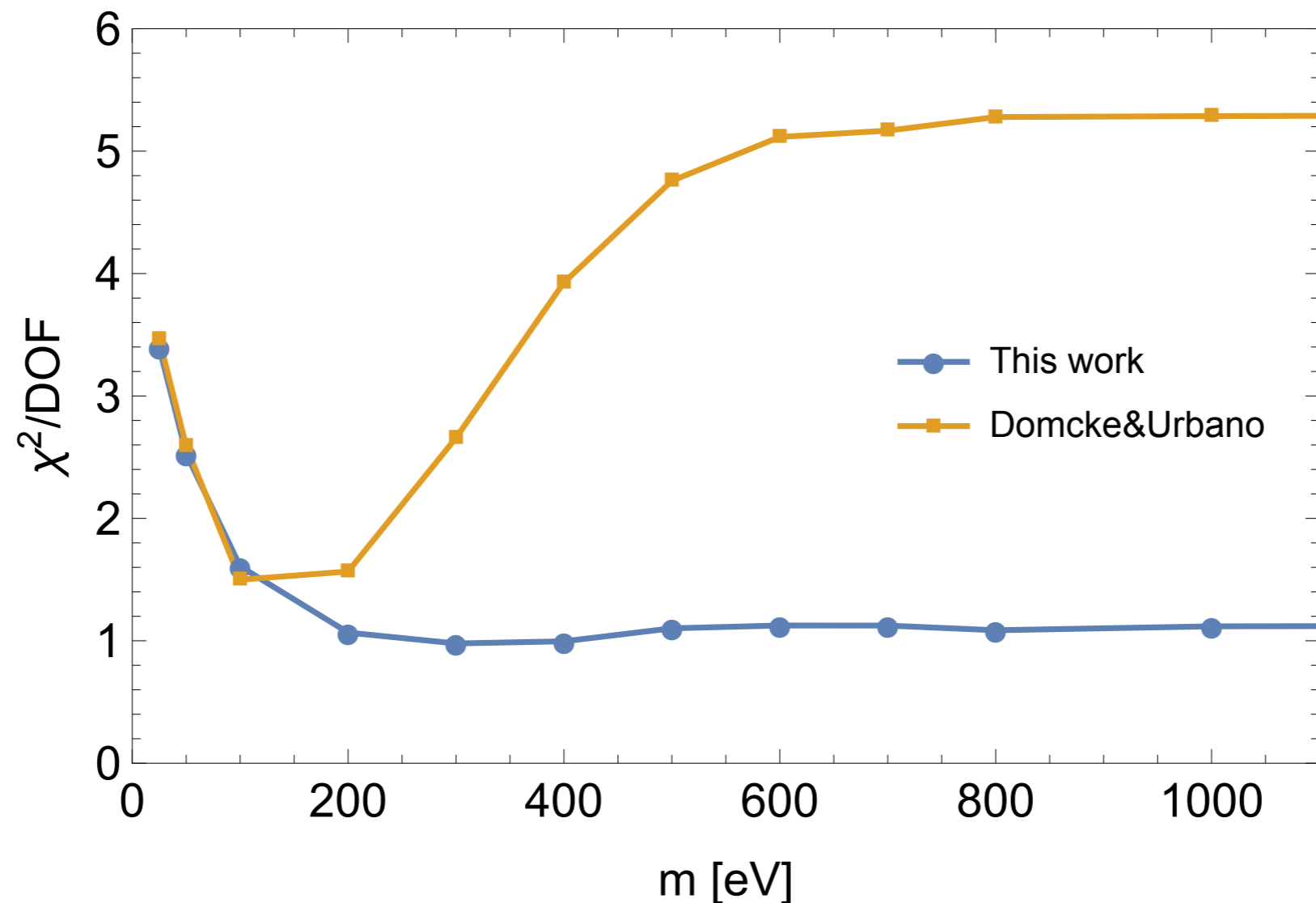
Carina, $m_f=200\text{eV}$ Draco, $m_f=200\text{eV}$ Fornax, $m_f=200\text{eV}$ Leo I, $m_f=200\text{eV}$ Leo II, $m_f=200\text{eV}$ Sculptor, $m_f=200\text{eV}$ Sextans, $m_f=200\text{eV}$ Ursa Minor, $m_f=200\text{eV}$ 

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Core/Cusp: Fits



There are additional constraints we need to include...

Fun/Future

- How to discover this framework? Are there only model-dependent consequences?
- Can we build a phase diagram of the Universe: different portal strengths lead to freeze-out, freeze-in and relative redshifting.
- Can we model build the small couplings as:
 - A. non-perturbative effects between two sectors of a broken symmetry?
 - B. a kinetic mixing parameter?
 - C. higher dimensional operator suppressed by a large scale?
- Could Φ be a modulus associated with a flat direction in the SM?

Summary

- This is a **framework** for an alternate cosmology with generic initial conditions.
- Motivated by: Standard Model **dominates the entropy density** of the Universe (we don't see other relativistic dofs.)
- It produces **sub-thermal** dark matter, which solves the **core/cusp problem** for dwarf galaxies.
- Nice setup for Freeze-in scenarios.
- It predicts that the sector with **long-lived heavy** particles ends up with the largest entropy density and is **very disconnected** from the rest of the Universe (sad!),
“Maximum baroqueeness”.

THANK YOU

Core/Cusp: core radius

$$R_c^6 \rho_c = \text{const}$$

vs

$$R_c \rho_c = \text{const}$$

[1501.06604]
[1506.05471]

